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# Optical FIBer Intrusion LOCation Sensor System (FIBLOC) For Surface and Subsurface Perimeter Protection

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Technical Report

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FIBLOC denotes a fiber optic intrusion location sensor system, it is based on a U.S. patent held by ANRO Engineering, Inc., and the FIBLOC trademark has been allowed. The physical basis of the sensor rests on the (phase) sensitive interference phenomena which govern propagation of an off-axis optical/infra-red beam through a graded index fiber.

A demonstration FIBLOC system, 100 meters in length and capable of localizing points of intrusion within 10 meters was constructed. The processor yields negligible false alarm rates and applies signal discriminants to identify the likely intruder as runner, walker or crawler. The system is ready for Phase III application and commercial development.

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Perimeter Protection — Intruder Location and Classification

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## SUMMARY

This is a summary of the results of a 2 year, Phase II SBIR program, termed FIBLOC, an acronym for FIBer optic intrusion LOCation system to develop a perimeter detection sensor for protecting important assets. The sensor employs fiber optic cable techniques to both locate the point of intrusion (e.g., within Δ meters) and identify the class of intrusion; for example, crawler, walker, runner or vehicle. The physical basis for the sensor depends on the (phase) sensitive interference phenomena which govern propagation of an off-axis optical/infra-red beam through a graded index fiber.

A perimeter sensor is one member of the class of intrusion detection sensors which include radar, sonic and ultra-sonic, piezoelectric devices and others. The FIBLOC sensor is designed to be used for either permanent or relocatable deployment and can be used both on and below the ground or in a fence. The sensor has a maximum range estimated to be 4 km. By virtue of a multiple fiber design it provides a significant degree of redundancy and hence can have an arbitrarily low false alarm rate: the trade-off is $P_{fa}$ vs cost of fibers.

ANRO teamed on this project with Optical Technology (OPTECH), Herndon, VA, whose primary task was to develop the fiber optic cable necessary for the FIBLOC sensor. OPTECH investigated different schemes of coupling the laser sources to the fibers as well as manufacturing the cable. The FIBLOC scheme uses a multiplicity of parallel fibers each Δ meters different in length. The original scheme involved a series of fiber loops of different lengths, but the loop junction was too difficult to reliably fabricate. Instead, OPTEC developed a scheme to simplify the manufacturing process by mirroring the ends of each fiber creating an optical short circuit and complete reflection of individual 0.83 micron laser sources (e.g., one for each fiber). Using mirrored ends instead of loops added the requirement for an optical coupler with each fiber.

Electronics and logic were developed to identify the entry sector along the cable as well as intruder identification. A conventional frequency domain approach was also taken to identify the signature an intrusion as measured by optical detectors and zero-crossing counters. It was found the electrical signature from fibers within the same cable produced very different results. Extensive field tests were conducted at ANRO's laboratory in Rochester, N.Y. As a result of these tests, it was found that the time duration of a disturbance was a much better signature determining measure than the rapid variations of the signal. Redundancy was added by requiring that at least two adjacent length fibers produced the same signature before an indication is made.

A demonstration of the FIBLOC sensor was made to DNA and interested government personnel in the Washington, D.C. area. Based on the results of these tests the electronics were modified for further false alarm reduction. The improved FIBLOC sensor was successfully demonstrated at Hanscom Field, Bedford, MA in May, 1993.

The FIBLOC intrusion detection sensor system has successfully met the design goals of a probability of detection of near unity for most classes of intrusion events, with an acceptable low probability of false alarm. In addition, FIBLOC provides identification of both the location of an intrusion within a predefined span, and the type of intruder, e.g., a walking person, a crawler or a vehicle. The FIBLOC sensor will be carried forward into Phase III to pursue commercial production for both government and private applications. The cost of the FIBLOC sensor is estimated to be less than $9/foot.

# CONVERSION TABLE

Conversion factors for U.S. customary to metric (SI) units of measurement

| To Convert From | To | Multiply |
|---|---|---|
| angstrom | meters (m) | 1.000 000 X E–10 |
| atmosphere (normal) | kilo pascal (kPa) | 1.013 25 X E+2 |
| bar | kilo pascal (kPa) | 1.000 000 X E+2 |
| barn | meter$^2$ (m$^2$) | 1.000 000 X E–28 |
| British Thermal unit (thermochemical) | joule (J) | 1.054 350 X E+3 |
| calorie (thermochemical) | joule (J) | 4.184 000 |
| cal (thermochemical)/cm$^2$ | mega joule/m$^2$(MJ/m$^2$) | 4.184 000 X E–2 |
| curie | giga becquerel (GBq)* | 3.700 000 X E+1 |
| degree (angle) | radian (rad) | 1.745 329 X E–2 |
| degree Fahrenheit | degree kelvin (K) | $t_K=(t^\circ f + 459.67)/1.8$ |
| electron volt | joule (J) | 1.602 19 X E–19 |
| erg | joule (J) | 1.000 000 X E–7 |
| erg/second | watt (W) | 1.000 000 X E–7 |
| foot | meter (m) | 3.048 000 X E–1 |
| foot–pound–force | joule (J) | 1.355 818 |
| gallon (U.S. liquid) | meter$^3$ (m$^3$) | 3.785 412 X E–3 |
| inch | meter (m) | 2.540 000 X E–2 |
| jerk | joule (J) | 1.000 000 X E+9 |
| joule/kilogram (J/Kg) (radiation dose absorbed) | Gray (Gy) | 1.000 000 |
| kilotons | terajoules | 4.183 |
| kip (1000 lbf) | newton (N) | 4.448 222 X E+3 |
| kip/inch$^2$ (ksi) | kilo pascal (kPa) | 6.894 757 X E+3 |
| ktap | newton–second/m$^2$ (N–s/m$^2$) | 1.000 000 X E+2 |
| micron | meter (m) | 1.000 000 X E–6 |
| mil | meter (m) | 2.540 000 X E–5 |
| mile (international) | meter (m) | 1.609 344 X E+3 |
| ounce | kilogram (kg) | 2.834 952 X E–2 |
| pound–force (lbf avoirdupois) | newton (N) | 4.448 222 |
| pound–force inch | newton–meter (N·m) | 1.129 848 X E–1 |
| pound–force/inch | newton/meter (N/m) | 1.751 268 X E+2 |
| pound–force/foot$^2$ | kilo pascal (kPa) | 4.788 026 X E–2 |
| pound–force/inch$^2$ (psi) | kilo pascal (kPa) | 6.894 757 |
| pound–mass (lbm avoirdupois) | kilogram (kg) | 4.535 924 X E–1 |
| pound–mass–foot$^2$ (moment of inertia) | kilogram–meter$^2$ (kg·m$^2$) | 4.214 011 X E–2 |
| pound–mass/foot$^3$ | kilogram/meter$^3$ (kg/m$^3$) | 1.601 846 X E+1 |
| rad (radiation dose absorbed) | Gray (Gy)** | 1.000 000 X E–2 |
| roentgen | coulomb/kilogram (C/kg) | 2.579 760 X E–4 |
| shake | second (s) | 1.000 000 X E–8 |
| slug | kilogram (kg) | 1.459 390 X E+1 |
| torr (mm Hg, 0°C) | kilo pascal (kPa) | 1.333 22 X E–1 |

*The becquerel (Bq) is the SI unit of radioactivity; Bp = 1 event/s.

**The Gray (Gy) is the SI unit of absorbed radiation.

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## FIGURES

FIGURES (Continued)

# SECTION 1

# INTRODUCTION

## 1.1 GENERAL.

This final report describes work performed under a PHASE II SBIR Contract No. DNA 001-90-C-0038 by ANRO Engineering, Inc.,[1] and its principal subcontractor, Optical Technologies (OPTECH) subsidiary of Dynamic Systems, Inc. The FIBLOC system concept, preferred configuration Figure 1-1 and alternate configuration Figure 1-2, provides effective sensing means for protection of precincts that may rapidly be deployed over the surface or concealed in the ground to guard against unauthorized intrusion. The FIBLOC system, US Patent 4,931,771, owned by ANRO, localizes the point of a sensed attempt at intrusion with precision corresponding to a fixed segmentation along the sensor cable.

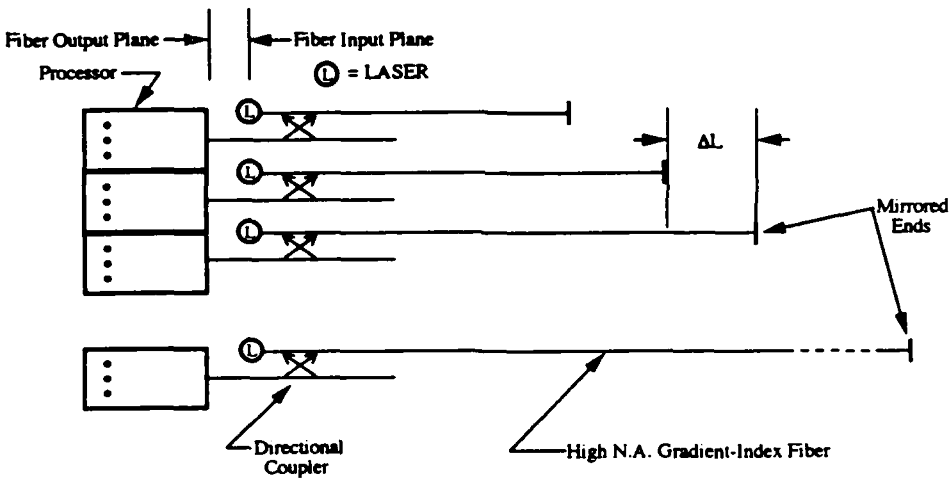



**Figure 1-1. FIBLOC system, mirrored (virtual loop) sensor preferred configuration.**

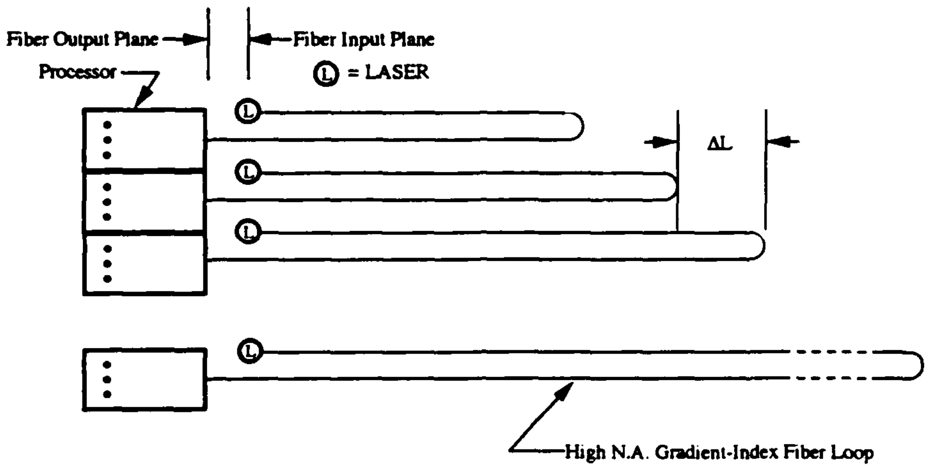



**Figure 1-2. Alternative experimental sensor cable configuration.**

ANRO Engineering, Inc., and its principal sub-contractor, OPTECH (acquired during the life of the contract as a division of Dynamic Systems, Inc.) have constructed a complete demonstration model of the system. The model FIBLOC system comprises the following components: a sensor cable assembly, laser source assemblies, detector-receiver assemblies, and signal processor alarm assemblies.

The physical basis of the sensor rests on the (phase) sensitive interference phenomena in the propagation of an off-axis coherent optical/infra-red beam through a graded index fiber. Because the system senses dynamic changes in its environment, it is only sensitive to the initial deployment conditions. For the same reason, it is ready to detect subsequent independent intrusions separated in time by seconds. An inexpensive processor provides discrimination with adjustable threshold for automated detection with low false alarm rate. The information content of the signals generated in this system provides a basis for intruder classification.

Each fiber circuit in the sensor cable is represented by a set of three colored lights. Extensive field tests of the FIBLOC sensor performed at ANRO's field laboratory in Rochester, N.Y., showed that a dominant signature characteristic of various different modes of intrusion was the *duration* of the signal disturbance. The logic design used in the demonstration model illuminates either a red, a green or an amber light to announce an intrusion depending on the time the

intruder is over a given fiber. The red light (the most dangerous situation) represents a crawler, a green light signifies the probability of a runner or vehicle, while an amber light indicates a possible walker. Any sensed intrusion will also activate an audible alarm. In the model demonstrated on October 3, 1992, at the Fort Belvoir Proving Grounds, Belvoir RD&E Center, U.S. Army ATCOM, Fort Belvoir, Virginia, Figure 1-3, manual switches were provided to reset the alarm, lights and sound. The partition between illuminated and dark sets of lights fixed the sensor segment over which the intrusion has taken place. An improved version introducing redundancy to reduce false alarms was demonstrated at Hanscom Field, Bedford, MA on May 13, 1993.

This Phase II development has successfully produced an innovative perimeter intrusion detection sensor system that exhibits a probability of detection and location of an intruder of near unity for most types of events, with a very low probability of false alarm. The system can also locate the intrusion, and determine the type of intruder. The FIBLOC sensor is ready for Phase III implementation and commercial exploitation.

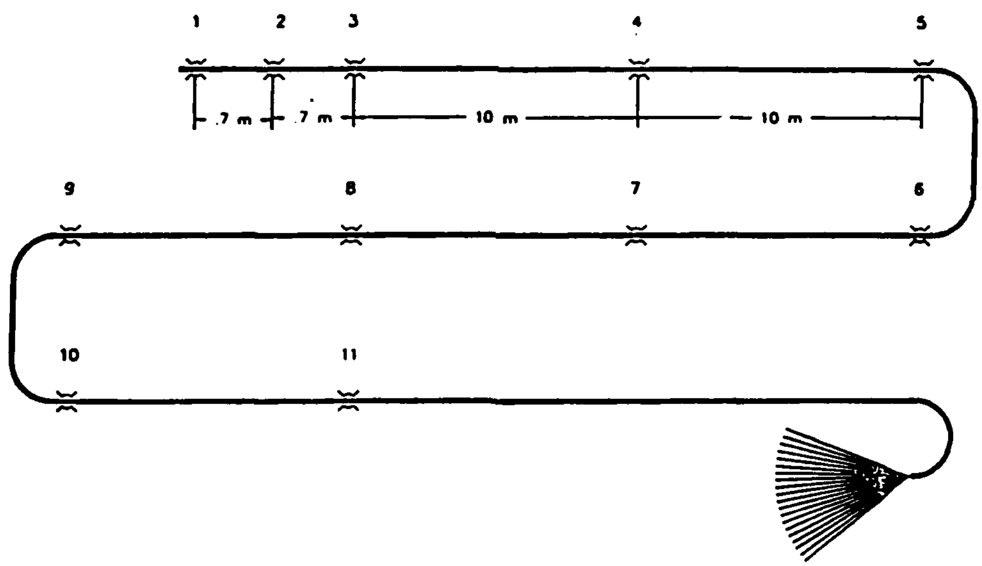



**Figure 1-3. Demonstration FIBLOC sensor cable.**

## 1.2 ORGANIZATION OF THE REPORT.

Section 2 of this report describes the evolution of the FIBLOC cable design. It includes a description of several trial efforts based on the use of loops to define the intrusion region in place of the preferred embodiment of mirrored fiber ends. The electronics used to determine the point

of entry as well as intruder signature is presented in Section 3. The first approach using spectral zero crossings was replaced with a simple scheme of measuring the duration of the disturbance and relating this to signature as described above. A description of the FIBLOC hardware and a description of the experimental results on signature is given in Section 4. Suggested modes of deployment of the sensor are described in Section 5. Conclusions and Recommendations are given in the final Section. Four Appendices are given which described the cable manufacture: (A) Designs for fabrication of a specialized FIBLOC cable, (B) Certain Manufacturers specifications, (C) a comparison of other perimeter protection schemes, and finally, (D) a copy of the FIBLOC patent and Trademark.

## SECTION 2

## FIBLOC CABLE DESIGN AND FABRICATION

### 2.1 THE FIBLOC SENSOR CABLE.

Several approaches to FIBLOC cable design and fabrication were investigated. These included purchasing a cable produced to specifications by a cable manufacturer, a cable produced in-house, and custom modification of a commercially-available cable. Each approach was studied to determine feasibility, advantages and disadvantages. A brief description of each alternative is given below.

### 2.2 PREMANUFACTURED CABLE.

Early in the effort, Rochester Cable Corporation located in Culpeper, Virginia was contacted to discuss the FIBLOC requirements. A tour of Rochester's facilities was taken to view the cable manufacturing capabilities. After the tour, discussions centering on the specific design requirements were held.

The initial design of the FIBLOC multi-fiber cable called for hairpin loops to be formed in individual fibers at 10 meter intervals (refer to Figure 2-1). Each fiber loop formed one sensing channel. Since 10 channels were desired in an experimental cable, 20 fibers were required. An overall cable length of 100 meters was used. The 20 fiber cable has an approximate diameter of 0.5 inch. Thus, for each loop the hairpin turn must be confined within this diameter. As a result, the stress on the fiber loops is near the proof strength. In the manufacturing process, the outer jacket of the cable is extruded under pressure. This process would tend to increase the stress in the loops. During the discussions with Rochester, it was decided that the increase in stress would most likely break the fiber. Furthermore, the manufacturer would not guarantee the optical continuity of the cable after manufacturing. Finally, an alternate approach suggested by Rochester was estimated to be too costly.

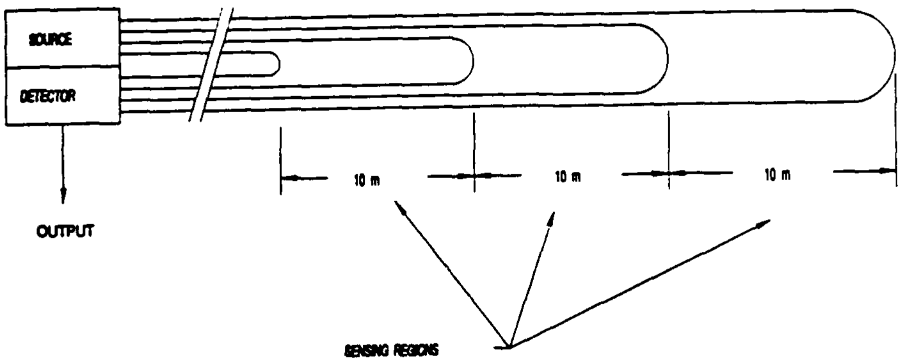



**Figure 2-1. Schematic of loop design.**

## 2.3 HAND-MADE CABLE.

An in-house approach to the cable design and fabrication was investigated. Two production methods were identified. The first technique utilized a closed-cell foam core with an interlocking outer jacket. The hairpin loops were made by winding the middle region of the fiber lengths around the circumference of small plastic disks. The disks were subsequently imbedded into the foam core. The fiber was loosely laid about the foam core and the outer jacket sealed. Problems related to the loose-fiber construction arose when the assembly was bent. These included shifting and bundling of the fibers within the outer jacket. Furthermore, during temperature cycling, the outer jacket became brittle and cracked when bent. These deleterious effects prompted investigation of a second technique of production.

The second technique incorporated the foam core with helically-wound fiber and a helically-wound outer jacket. The specific method of construction attempted to mimic widely-used cable manufacturing procedures. It became apparent that specialized tooling and equipment were required to perform the various operations. See Appendix A. In addition, proper construction materials for the outer jacket which could withstand the environment (e.g., sunlight, water absorption, and temperature) were not readily available. Finally, it was anticipated that this technique would require a labor-intensive effort and would result in less control of repeatability between sensing regions and cables.

## 2.4 CABLE MODIFICATION.

Modification of a commercially available cable to adapt it for use as FIBLOC sensor was investigated. The required modifications included stripping off a section of the outer jacket, creating a fiber loop (see section 1.1), and resealing the opened section. Two sample cables (man-

ufactured by Optical Cable Corp.) containing 4 and 24 fibers were selected. These cables were specifically chosen for their fiber type (50/125 μm graded index) and compatibility with outdoor/underground applications. The 4 fiber cable was modified to accommodate the fiber loops. The response of this cable was found to be acceptable. Work was performed on the 24-fiber cable to optimize the fabrication of the fiber loops. Fusion and mechanical splices were investigated. Fusion splices were selected due to their relatively small size and flexibility. The fusion splices were protected and potted (see Sections 2.5.3 and 2.5.4). Tests were performed on the 24-fiber sample cable. The response was found to be similar to that of the 4-fiber cable. Despite care and precautions in assembly, subsequent experience indicated that the loops formed in the FIBLOC cable were too fragile to function reliably in the field.

To increase reliability and simplify the design, mirrored fiber ends were substituted as a replacement for the fiber loops. Thus, the light travels down and back through a single fiber. A multimode 3 dB coupler/splitter (C/S) is used at the input end of the channel (See Figure 2-2). Light from the source is launched into the input arm of the C/S. This light is split equally by the C/S into two output arms, one of which is coupled to the sensing channel. The reflected light is monitored at the output port of the C/S. This manufacturing approach was found to be the most successful, and is presently used in the FIBLOC system.

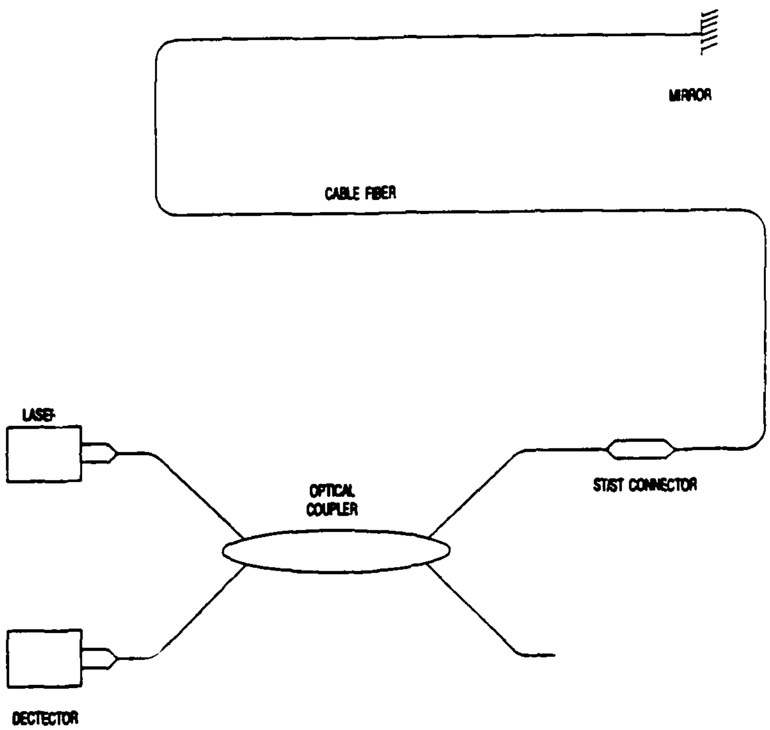
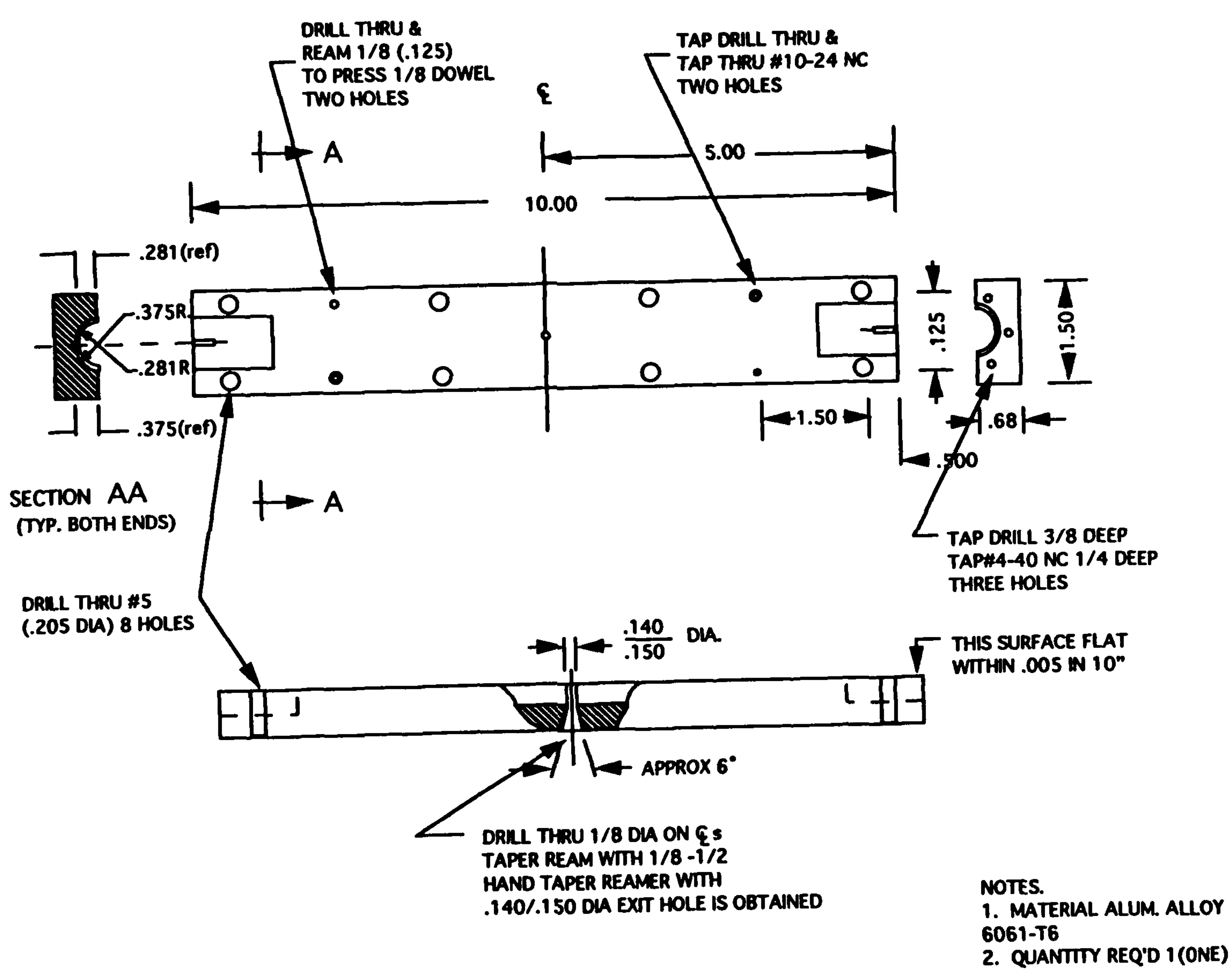


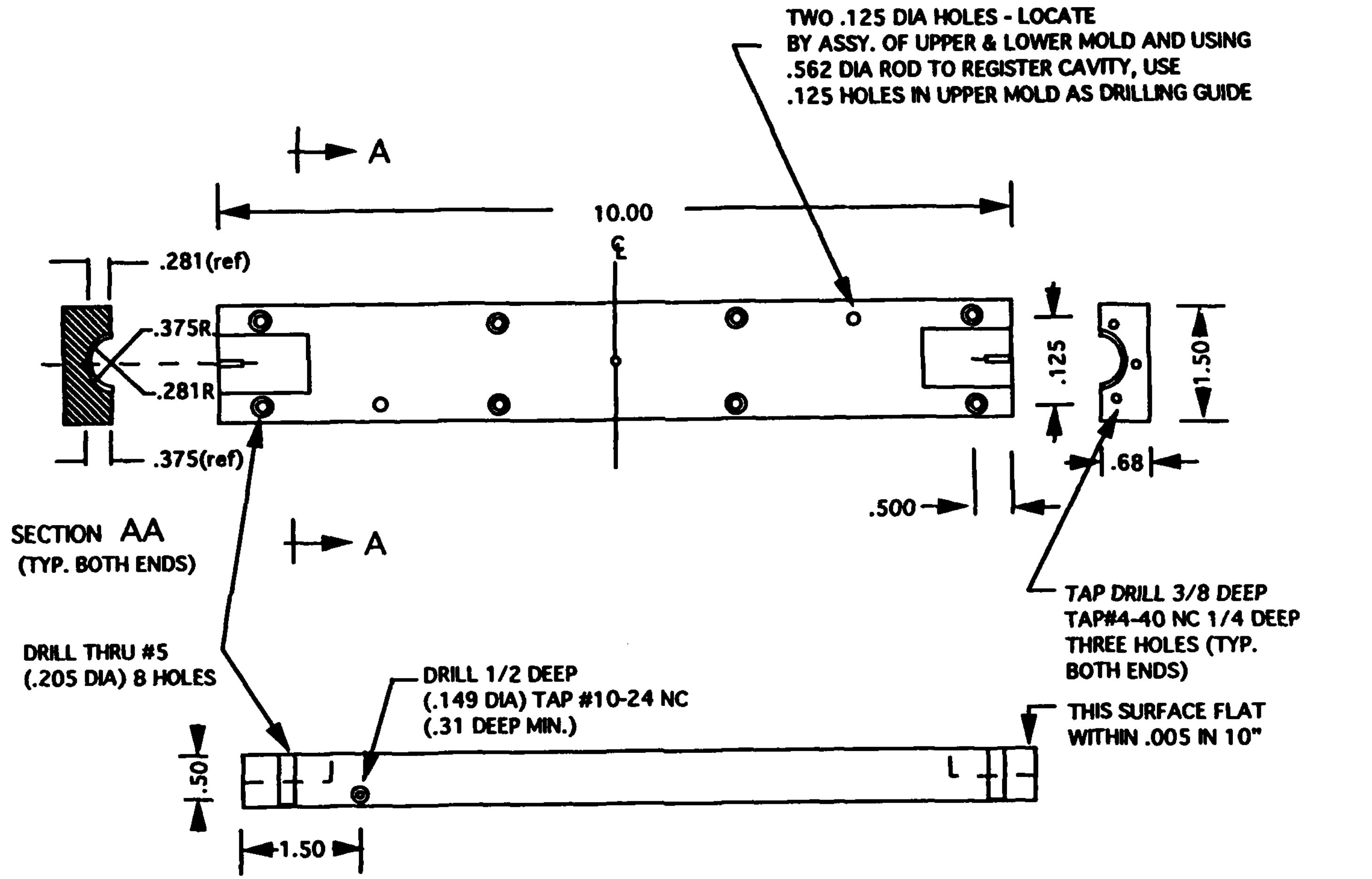

**Figure 2-2. Schematic of mirrored fiber with coupler.**

## 2.5 FIBLOC CABLE FABRICATION.

The tools used to fabricate the FIBLOC cable having the mirrored ends include: a fusion splicer (Power Technologies PFS-330 or equivalent), a fiber cleaver (York FK-11 or equivalent), a cable break-in tool (Anixter part #123397), a fiber buffer stripping tool (Micro-Strip MS-FOK-1 or equivalent), a file, and a custom two-piece potting mold. The machine drawings for the mold are found in Figure 2-3. The step-by-step fabrication process of the FIBLOC cable is described below. Note that although the mirrored-end fiber technique was found to be preferred, a description of the fabrication process for the loop method is included for informational purposes.

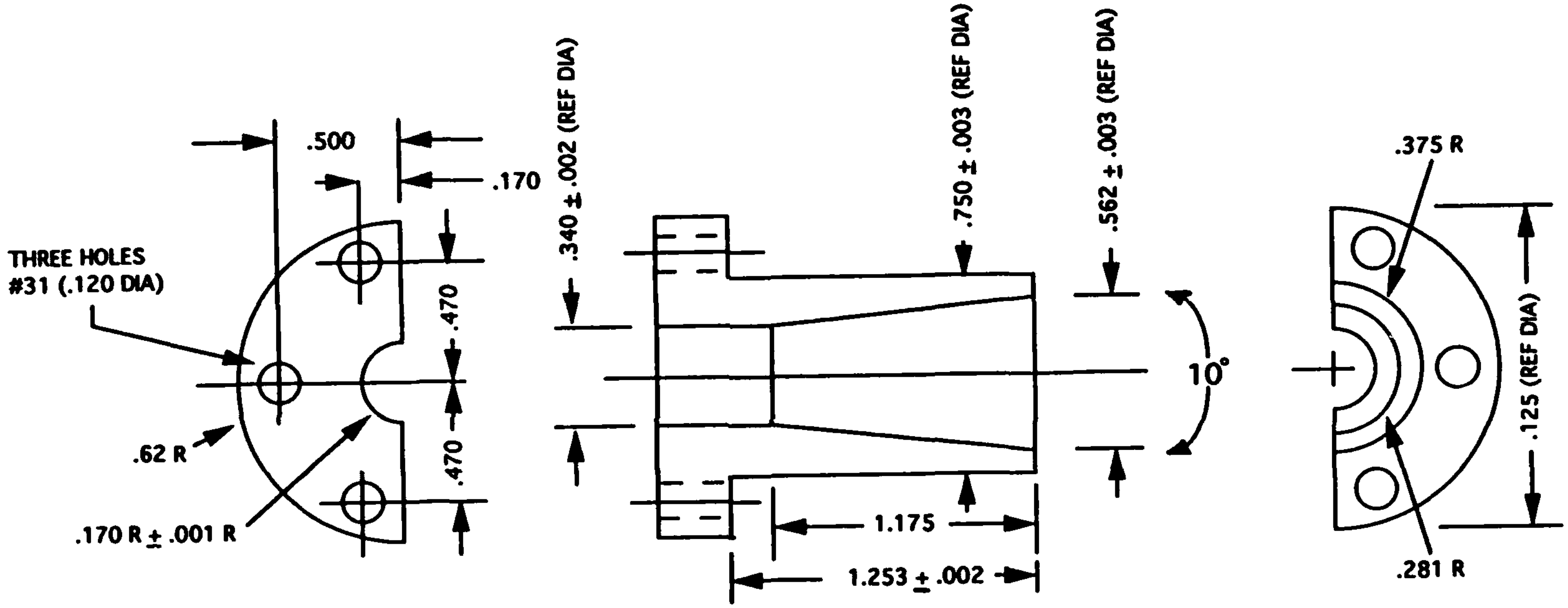



(a) Upper portion, splicer mold.
Figure 2-3. Intrusion sensor.



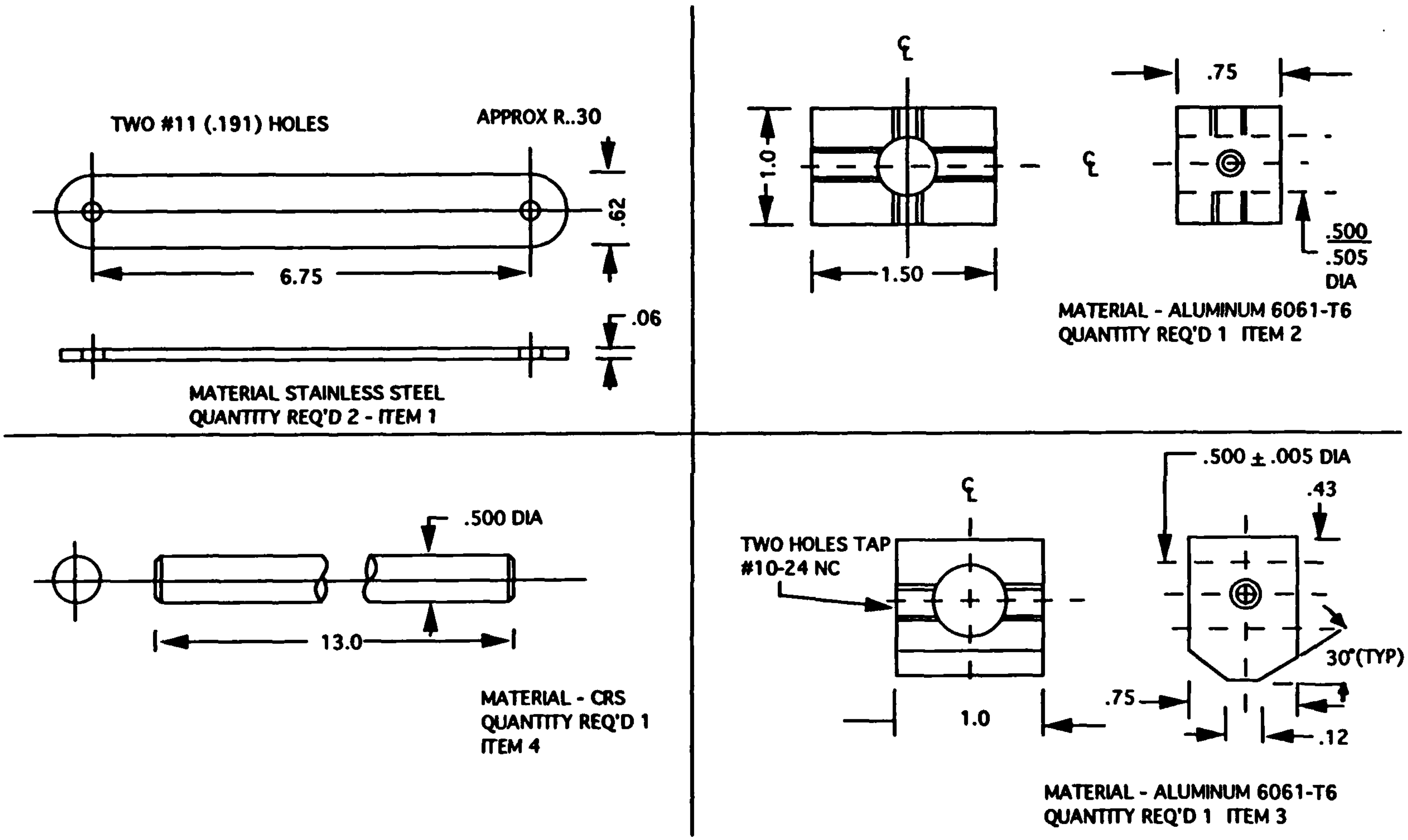

NOTES.
1. MATERIAL ALUM. ALLOY
6061-T6
2. QUANTITY REQ'D 1(ONE)

**(b) Lower portion, splicer mold.**
**Figure 2-3. Intrusion sensor (Continued).**




NOTES:
1. MATERIAL - ALUMINUM 6061-T6
2. QUANTITY REQ'D 4 (FOUR)

**(c) End bushing, splicer mold.**
**Figure 2-3 Intrusion sensor (Continued).**




**(d) Injection handle, splicer mold.**
**Figure 2-3 Intrusion sensor (Continued).**

### 2.5.1 Cable Set-Up.

A lay-out bench is recommended for unreeling the FIBLOC cable. Three capstans spaced approximately 3.5 meters apart are used to guide the cable. This spacing allows for a 10 meter span between channels before the cable is wound on a take-up reel. The first sensing channel is located approximately 3 meters from the input end of the cable. The cable break-in tool is used to cut and strip the outer jacket over a 6" length.

### 2.5.2 Channel Preparation.

The cable is slightly twisted so that the fibers and the Kevlar strength members become straight and not helical. The Kevlar strength members are separated, thereby exposing the buffered fibers. A fiber is selected and its color-code noted. A fiber is cut and stripped approximately 3" of its buffer. If loops are to be used, another fiber is similarly prepared. The fiber(s) are cleaved, leaving approximately 1/4" of bare glass.

### 2.5.3 Mirror/Loop Installation.

A segment of buffered fiber is prepared for mirroring by stripping and cleaving the ends. This segment has an approximate length of 1.5" after cleaving. All segments are prepared and mirrored at the same time. Chemical mirrors (e.g., silver) or sputtering techniques have been used. After an end face of the segment is mirrored, it is protected by a capillary filled with UV-curable epoxy. The mirrored segment is then fusion spliced to the host fiber and this splice is also protected.

If a loop is to be installed, the fiber segments which will form the (optical) loop are cut, stripped and cleaved. The approximate length of the segment should be 3" after cleaving. The segment ends are then fusion spliced to both host fibers. Each splice is protected by a capillary filled with UV-curable epoxy.

### 2.5.4 Reforming Cable Diameter.

When replacing the mirrored segment, the cable is again slightly twisted so that the fibers and Kevlar strength members become straight and not helical. The fiber is laid back into its original location, and the cable rotated back to the original helical twist. The Kevlar strength members wrap back around all the fibers.

When conforming the loop around the opened section, the cable is held so that its original helical twist is maintained. The two fibers (i.e., those that make the loop) are loosely wrapped around the outside of the Kevlar strength members. The angle of the wrap should match the natural twist of the rest of the fibers. The loop will conform to the outside diameter of the cable's opened section and is held in place with a small piece of tape.

### 2.5.5 Preparation for Potting.

The opened section of the cable is wrapped with two layers of cellophane before it is placed in the mold. The layers are wrapped in opposite sense. Both halves of the mold are cleaned and sprayed with mold release (e.g., Crown 3065) each time before use. To ensure a good bond between the potting compound and the outer jacket, a rough file is used to roughen the surface of the jacket.

### 2.5.6 Potting Compound.

A potting compound (Uralite 3140) is used to fill the mold. The potting compound is injected into the mold, creating a protective covering.

### 2.5.7 Curing the Potting Compound.

The mold and compound are heated for about 30 minutes and allowed to cool.

### 2.5.8 Inspection.

The mold is then opened and inspected for air bubbles and/or other imperfections. The fiber channel is also checked for optical continuity.

## 2.6 CABLE SPECIFICATIONS.

The unmodified 24-fiber, 100 meter-length prototype FIBLOC cable is manufactured by Optical Cable Corporation located in Roanoke, Virginia. It is classified as a "D-Series" distribution cable (part # D24-080D-A3FB/1FC/900) suitable for indoor and outdoor applications. The cable consists of color-coded, 900 μm diameter tight-buffered optical fiber. Kevlar is used as the strength member. The pertinent specifications for this cable series are found in Appendix B. The cost is relatively independent of fiber count and is approximately $18.00/meter for lengths

up to 10 km. The cable and C/Ss were purchased with ST-style connectors installed. The C/Ss were obtained from Gould, Inc. (part # MM-C1A-50/50-02x02). The coupler specifications may also be found in Appendix B.

## 2.7 SUGGESTIONS FOR FUTURE IMPROVEMENTS.

Some suggestions for improvements to the FIBLOC cable are discussed herein. The mechanical properties of the potting compound should be matched to those of the outer jacket of the cable. This will restore the overall physical strength of the region of the cable where the splice is made.

To improve repeatability and reflectivity, the mirrors could be sputtered or vacuum-deposited onto the end faces of the fibers. The fibers comprising the cable might be mirrored prior to the extrusion of the outer protective jacket. This would eliminate the need to break the integrity of the outer protective jacket. The number of sensing channels may be increased to equal the number of fibers in the cable.

Another improvement is the use of state-of-the-art connectors such as FC/PC style. These connectors will minimize optical loss and drift due to temperature. They are available from a variety of suppliers.

# SECTION 3

# FIBLOC ELECTRONICS

## 3.1 INTRODUCTION.

The preferred embodiment of the FIBLOC perimeter sensing system is shown in Figure 1-1, where single fibers are fed from a laser source through an optical directional coupler to a mirrored termination. The distance from the input coupler to the mirror termination for each fiber is different in length by $\Delta$ L meters. This is the patented feature which is used to provide the means to locate the intrusion entry by the FIBLOC system. A signal caused by an intruder stepping on the fiber bundle is fed back to the source where it is coupled to a (4 quadrant) square law optical detector converting the rapid changes in light intensity into four varying currents. These are differenced in pairs. The difference output of the detector is ac coupled to a preamplifier having a gain of 14 dB. A high pass filter in cascade with the amplifier has a 3 dB cut-off frequency of 15.9 Hz. Following a second stage of amplification, a low pass filter having a cut-off of 450 Hz is inserted. The total effect is that of a bandpass filter (15.9 - 450 Hz) in the cascade connection of stages designed to discriminate against unwanted noise and yet detect expected signal variations of prime targets (see section 4). A final stage of gain feeds the logic which determines the location of the sector violated as well as the most probable cause of the intrusion (e.g., crawler, walker, vehicle, animal). The logic is designed to determine the character of the intrusion based on the duration of the disturbance. It was found by extensive field experiments that this was the most reliable and cost-effective discriminator.

## 3.2 THE LASER SOURCE.

The power level of the solid state, semi-conductor laser source used in each fiber for the demonstration system is 0.5 mw. This level was chosen to demonstrate the feasibility of the 5 segmented fiber cable having a maximum length of 50 meters. It was found during the laboratory and field tests that, on occasion, one of the lasers would excite a low level oscillation that caused the logic circuitry to false alarm. To quash this oscillation, it was determined that the placement of a 1 mm clear plastic spacer directly at the output of the laser source resulting in a 2.8 dB insertion loss, provided sufficient attenuation to eliminate the unwanted positive feedback. It is recommended that the next generation of this system employ as a separate unit a laser diode combined with an isolator source similar to Model PT-650-830 which in addition produces a 10 mw output for increased range; the cost of this source is currently near $1400. One source

is required for each fiber line. It should be noted that the prices of such laser sources equipped with isolation has been dropping rapidly, and it is believed that production costs for those devices should soon be in the $500 range. Alternately, it is recommended that three HeNe lasers feeding three 8:1 optical power dividers can be used where each laser costs about $400.

## 3.3 THE FIBLOC ELECTRONIC LOGIC DESIGN.

One of the primary problems of an intrusion detection system is the false alarm rate. False alarms can be caused by a number of factors ranging from earth rumbling due to, for example, a large passing truck to a damped oscillation caused by improper laser loading (as indicated in 3.2 above). However, by nature of the design concept, FIBLOC has the ability to take advantage of an inherently accessible checking feature (i.e., redundancy), to reduce false alarms to a negligible level. For example, for a decision to be made on an intruder signature two or more fibers can be sampled and the results ANDed for a logic level "1" determination of a valid target (see Section 3.5). Further, more than one cable bunch would normally be employed to assure for a high probability of detection that a intruder footprint will not be missed as described in "Modes of Deployment", Section 5. Results from multiple cables placed more closely together can also be ANDed to achieve a still further reduction of the probability of a false alarm. Still another approach suggested by Chinese investigators uses only a single cable, but at a much higher gain (see Section 4.5).

In the revised demonstration model, a footprint on any fiber lights an indicator. If, for example, only indicators 4 and 5 light, then it is clear that the intrusion occurs somewhere within $\Delta$ L meters in fiber 4. In this example, to determine the intruder signature, we test the outputs from lines 4 and 5 and require that we obtain similar *duration* disturbances from both fibers before a determination of an actual intrusion is made.

The logic circuit operation for signature analysis is shown in Figure 3-1. The output from a fiber which is amplified and filtered is shown in Figure 3-2 for two different types of intrusions. Note that the signal has an irregular pattern, but a compact duration. When any part of the signal exceeds the threshold, one shot (OS) #1 shown in Figure 3-1 is triggered. Its duration, set in accordance with Dr. DeLorenzo's experimental data, gathered at ANRO's Rochester, N.Y., test facility has a pulse duration of, say, 0.75 second(s) for a fast runner. The trailing edge of this

gate Q′ (#1) fires OS #2 while the Q′ (#2) fires OS (#3); those gates are shown staggered in Figures 3-2 (a) and (b) with the time durations indicated. The AND and NAND circuits are arranged so that if, for example, a signal is detected both in Fibers 4 and 5 only within the 0 - 0.75 second gate indicating that the intruder is a runner or a fast truck.

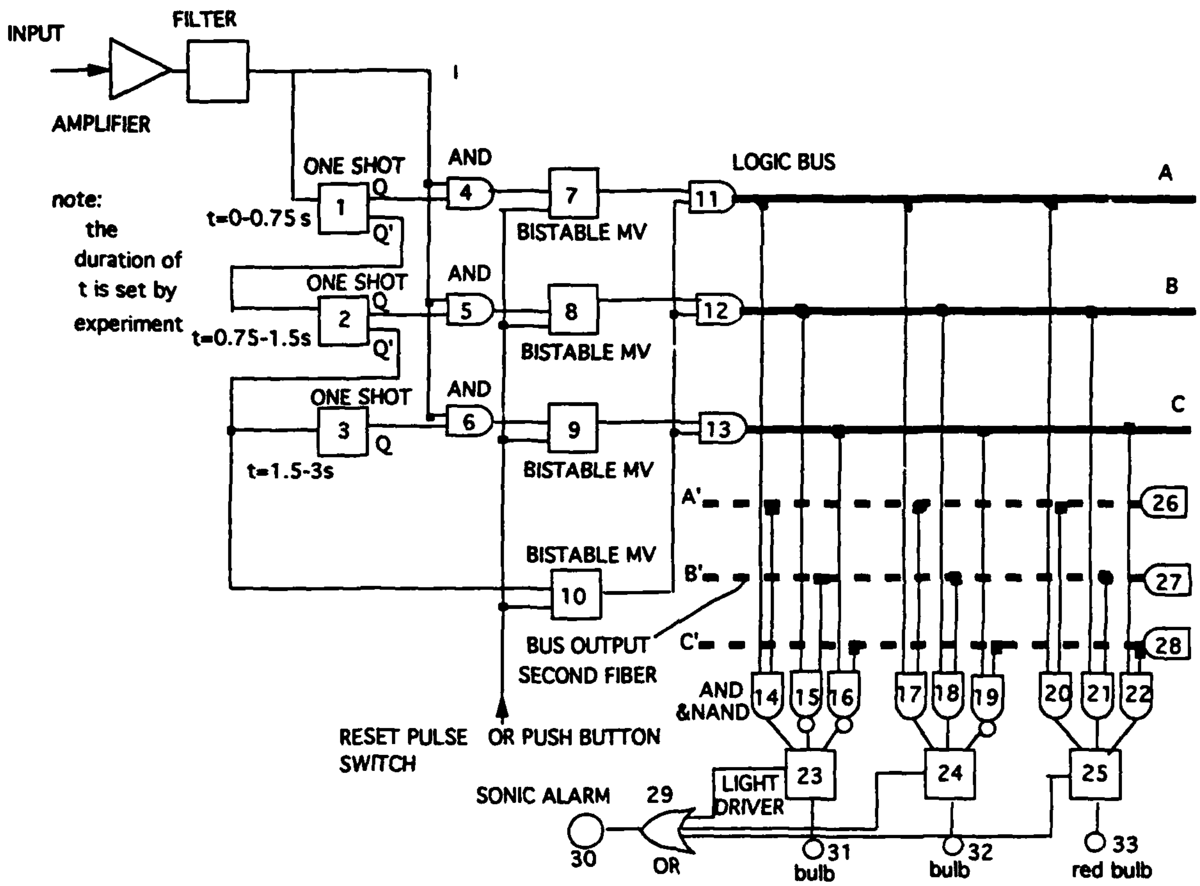
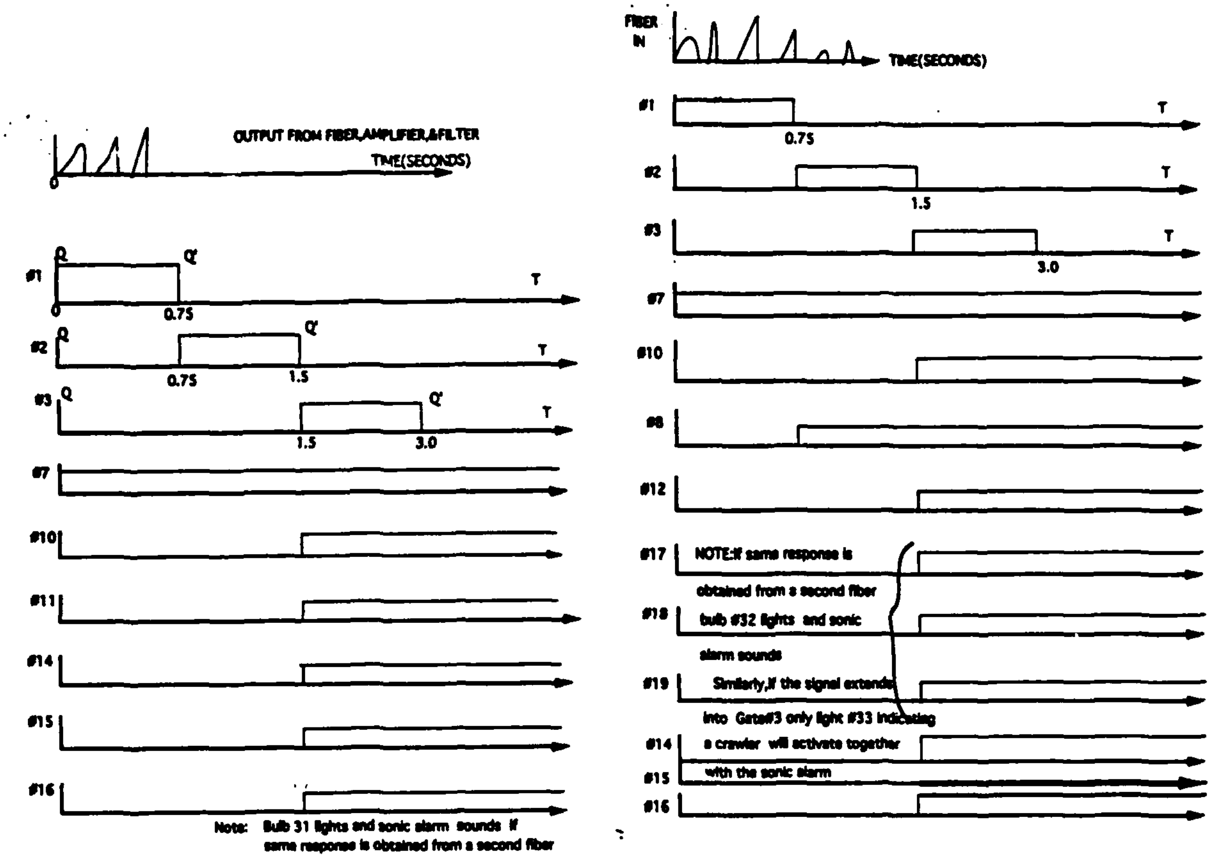



**Figure 3-1. Logic diagram.**

The initial demonstration model did not include the above logic for false alarm reduction. All 5 fibers, using the improved logic described above, were operated within the laboratory for several hours without any false alarms. The May, 1993 field demonstration to DNA and USAF personnel successfully incorporated the ANDing of two fibers. Since this logic was demonstrated an additional improvement described in Section 3.5 has been developed.

The details of the logic circuit operation for the case of a runner, Figure 3-2 (a), or a walker, Figure 3-2 (b) are as follows:




(a) Runner. (b) Walker.

**Figure 3-2. FIBLOC logic timing diagram.**

The signal and OS #1 are ANDed in network #4 (Figure 3-1) to cause the bistable multivibrator (BS) #7 to input a step function into AND #11. The trailing edge output Q′ of OS #2 fires BS #10 whose output is simultaneously fed to all AND networks #11, #12, and #13 as shown in Figures 3-2 (a) and (b). In this case, BS #7 fires placing a "1" on logic Bus A. Since logic busses B and C are 0, the AND circuit #14, the NAND circuits 15 and 16 will receive a "1", "1",

"1", pattern. If a second fiber produces a similar "1", "1", "1", pattern from its logic busses A′, B′, and C′, then light driver circuit #23 will activate the sonic alarm, #30 and bulb 31. Either an output from #23, #24, or #25 will also activate the sonic alarm.

Figure 3-2 (b) illustrates the anticipated waveform, say, for a walker. In this case only light #32 and the sonic alarm will sound. Similarly, for the crawler, only bulb #33 will light while also sounding the sonic alarm. A runner or fast moving vehicle would light indicator #31.

A single reset pulse (or switch) recycles the circuit. This reset is now initiated by the operator.

## 3.4 DETAILED FIBLOC ELECTRONIC CIRCUITRY.

### 3.4.1 Earlier Versions of the FIBLOC Circuitry Design.

Earlier work in the project took a more conventional approach to target or intruder signature analysis. A considerable amount of effort was expended in actually analyzing the signature caused by different classes of intruders. The output spectra was divided by filter design into 10 separate frequency bands or channels. A high pass filter (HPF) was placed in series with the output from the photo diode source to eliminate thermal drift. After the spectral data was separated, the filters outputs were fed to a series of T1-TL490 (10 stage) analog threshold chips which in addition to monitoring levels provided zero crossing in formation.

The schematic diagram of the original interface circuitry is shown in Figure 3-3. The output from each fiber is incident on a photo diode which feeds a bank of bandpass filters separating the spectral data as shown in Figures 3-4 (a) and (b) from 20-750 Hz. The output from the filters then feed to driver circuitry which activated the LED's shown in Figures 3-5 (a) and (b). A diagram of the basic zero crossing counting discrimination function is presented in Figure 3-6.

It was found from field experiments using this circuitry that the output from different fibers even from the same intruder footprint contained considerably different spectral data. Thus, the frequency sorting solution was not as effective as first thought in seeking an intruder discriminant. What Dr. DeLorenzo found, however, was that a time domain solution which measured the *duration* of an intruders disturbance as opposed to the spectral content determined by counting zero crossing was far more effective and simplified the electronic design considerably as described in the previous section. This was the approach that was adopted for the final design and for the demonstration system.

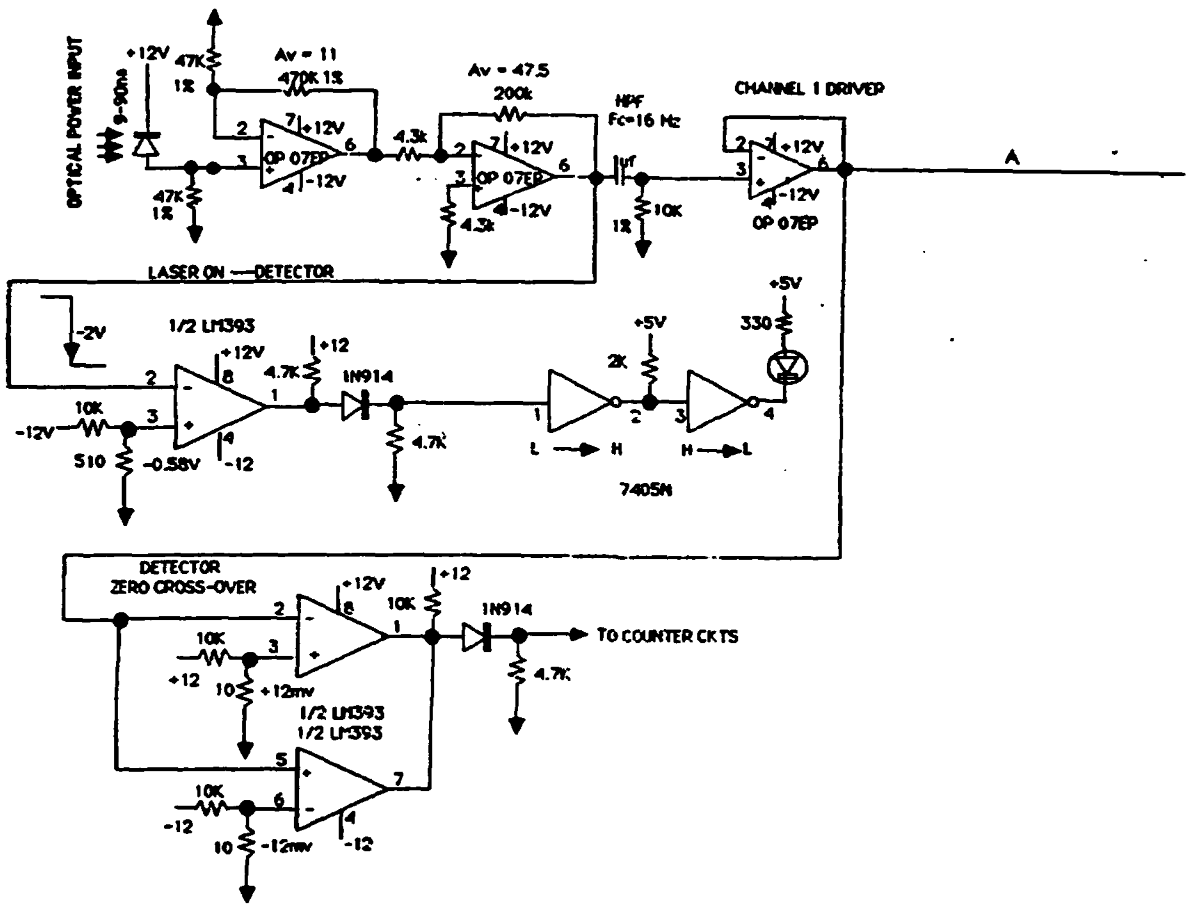
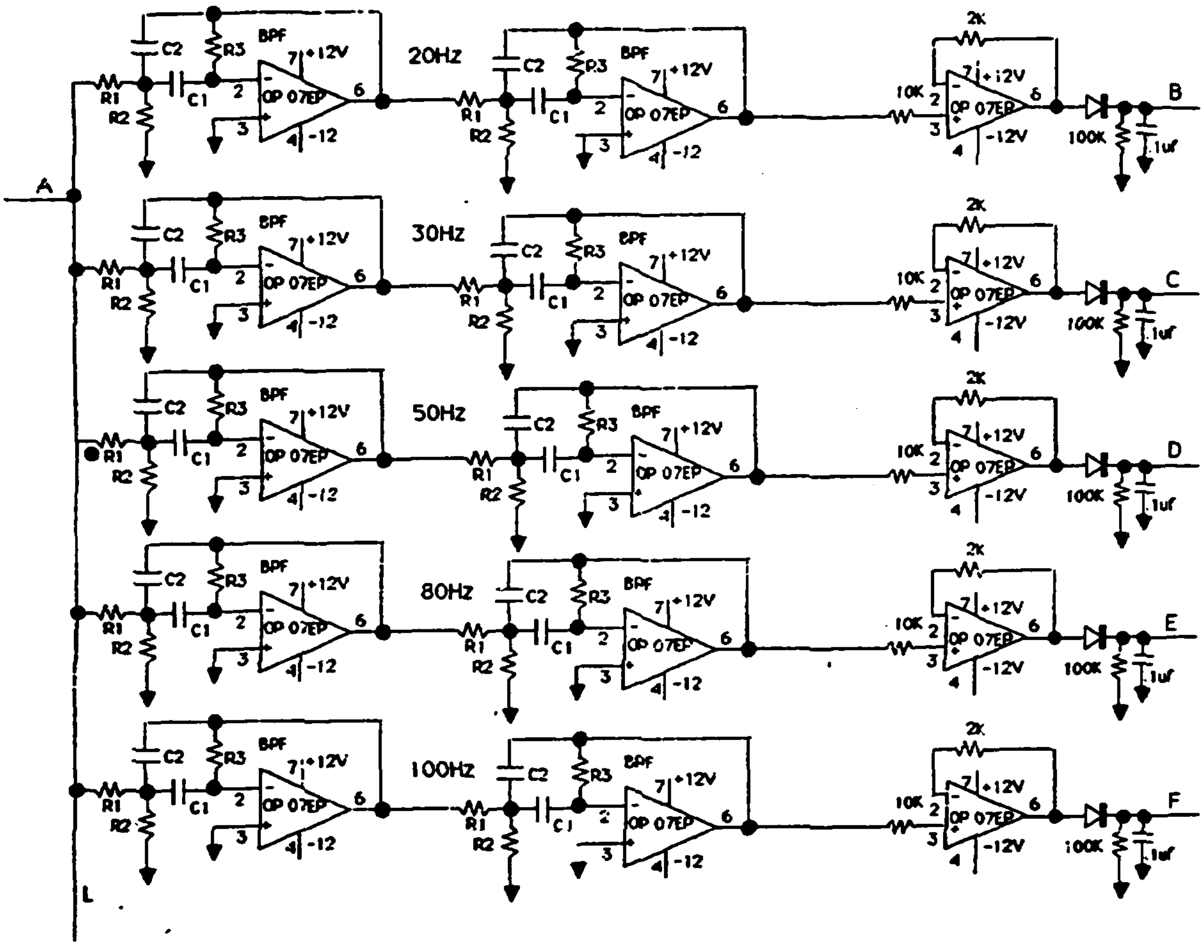
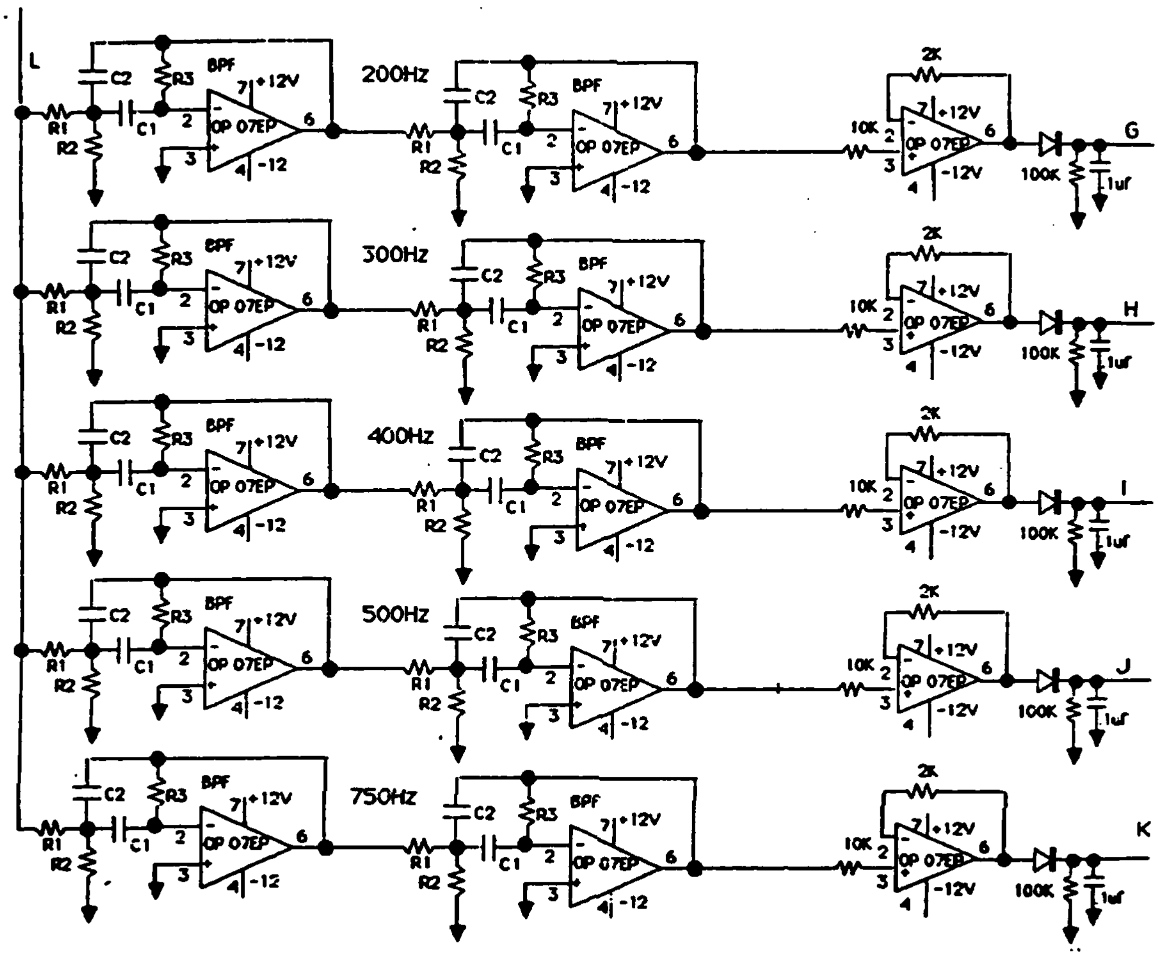



Figure 3-3. Original interface circuitry.



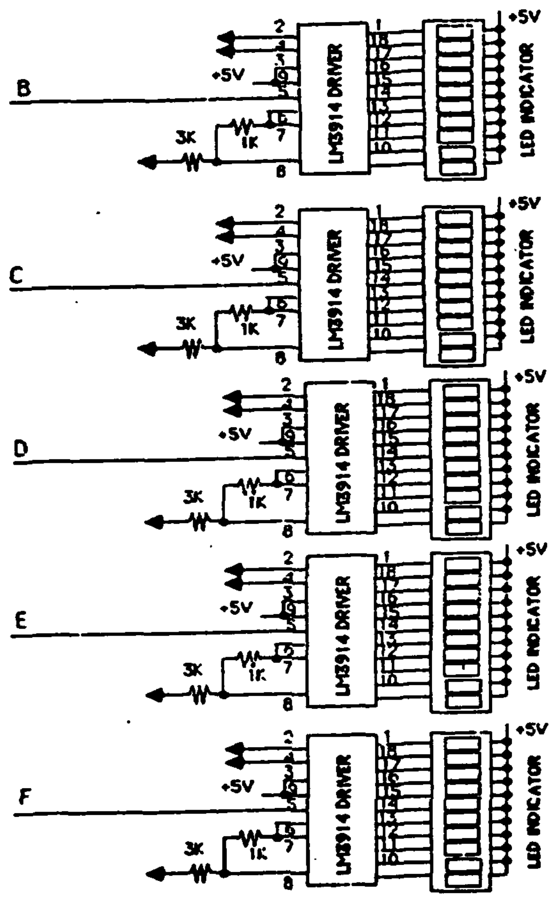

**(a) (20 Hz - 100 Hz).**

**Figure 3-4. Spectral separating filters.**



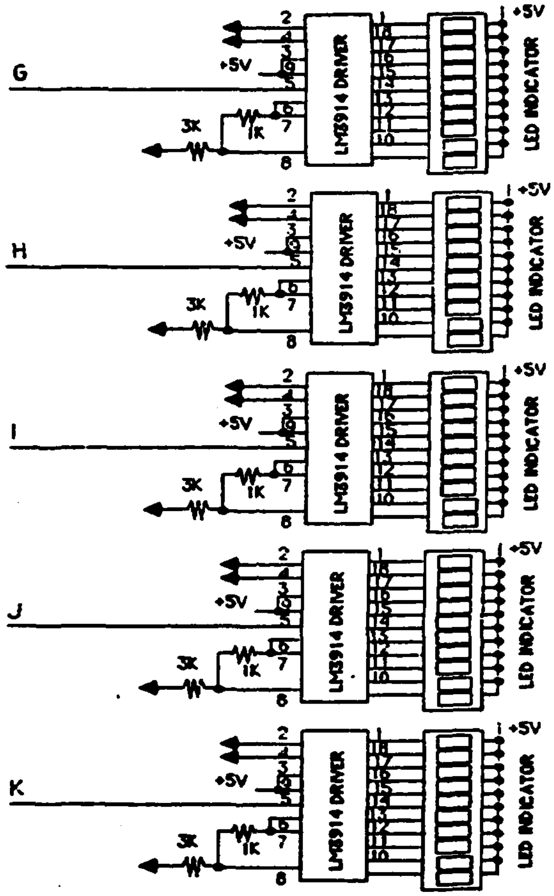

(b) (200 Hz - 750 Hz).

**Figure 3-4. Spectral separating filters (Continued).**




**(a) (20 Hz - 100 Hz).**

**Figure 3-5. Driver and indicator.**




**(b) (200 Hz - 750 Hz).**

**Figure 3-5. Driver and indicator (Continued).**

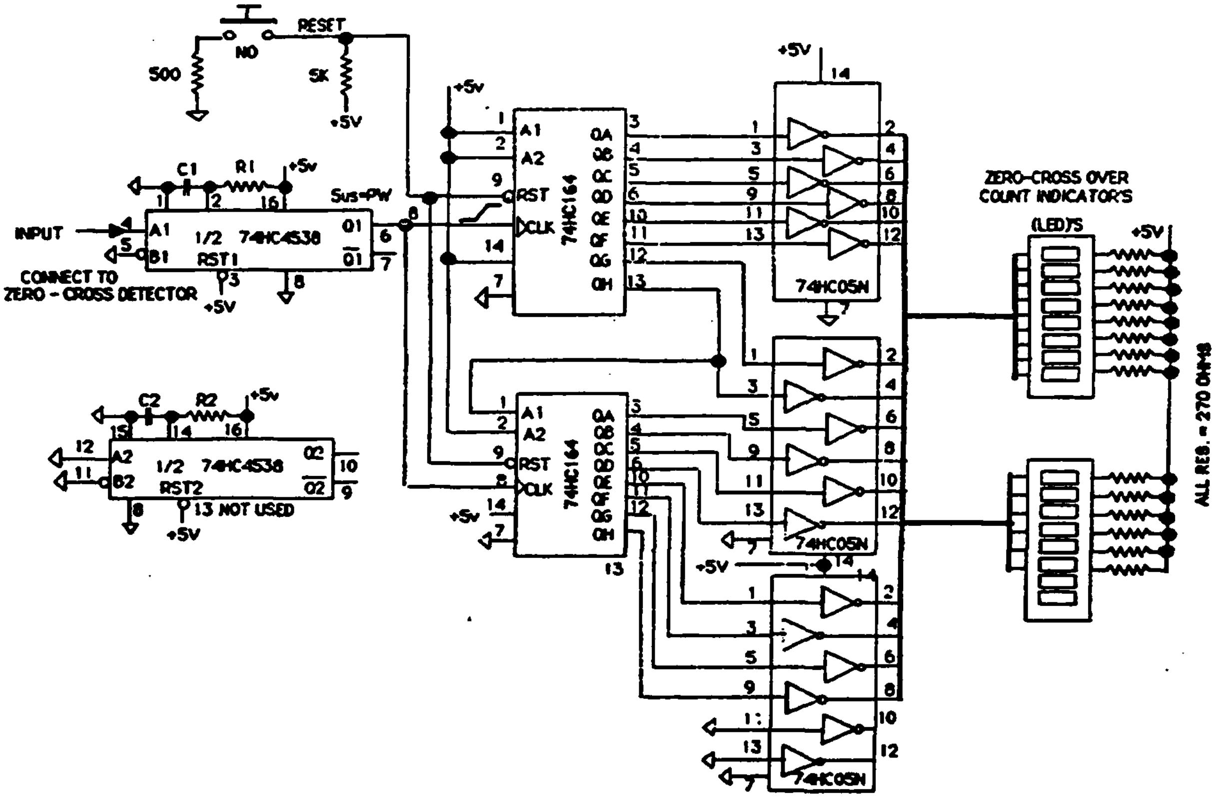



**Figure 3-6. Zero crossing-over counter.**

### 3.4.2 Finalized Circuitry.

A block diagram of the demonstration FIBLOC sensor is shown in Figure 3-7. A description of the laser diode mount and preamplifier circuit is shown in Figure 3-8, while the optical coupler is shown in Figure 3-9. The four quadrant detector design to maximize the signal output during a disturbance, and to minimize noise when the system in quiescent, and the four quadrant amplifiers are shown in Figure 3-10 (a) and (b).

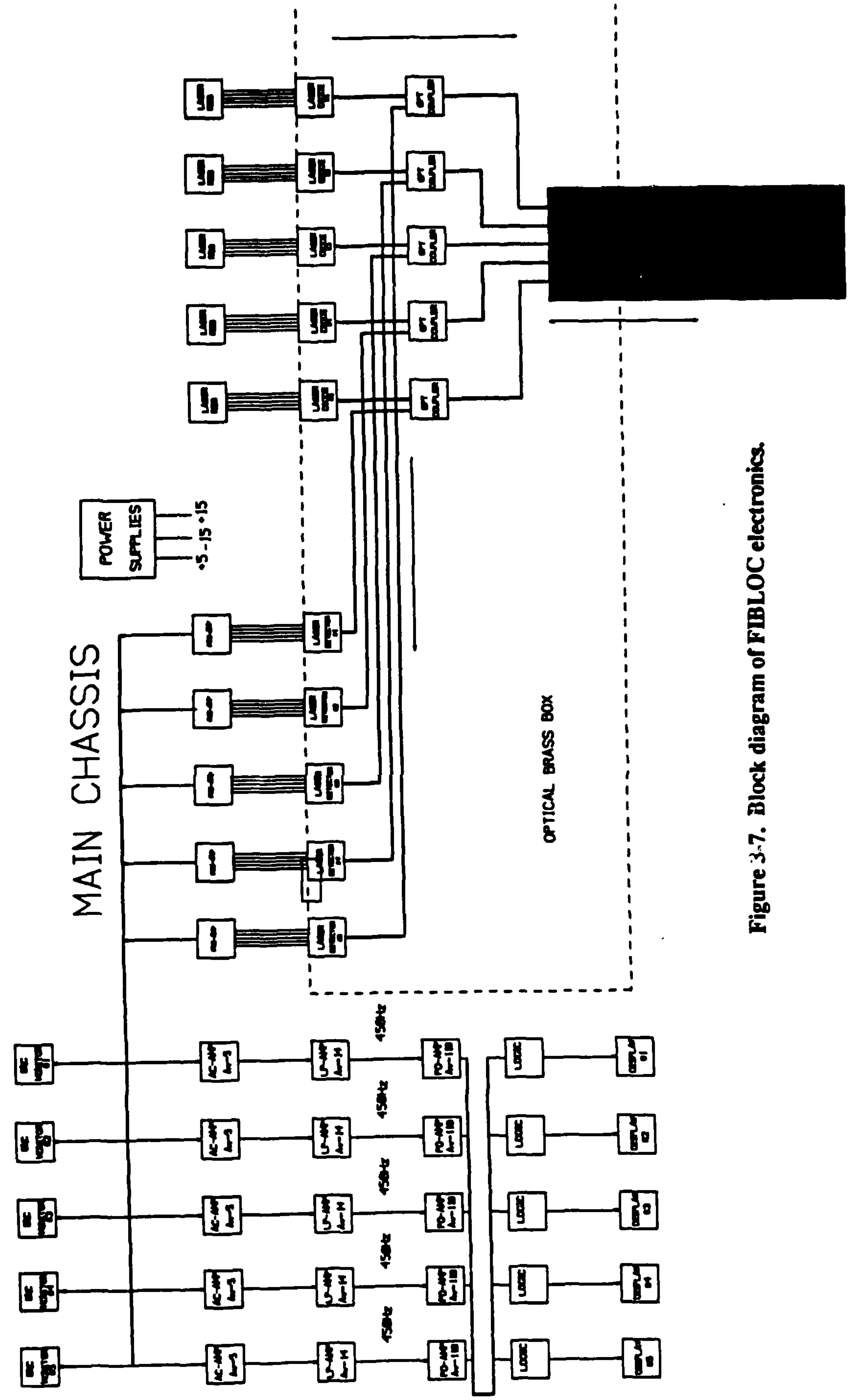



**Figure 3-7. Block diagram of FIBLOC electronics.**

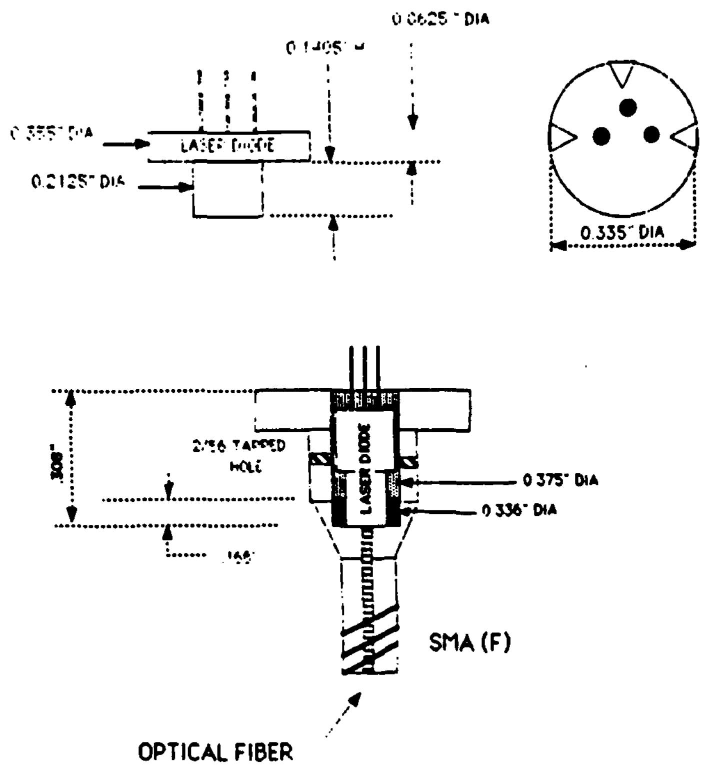



**Figure 3-8. Laser diode description.**

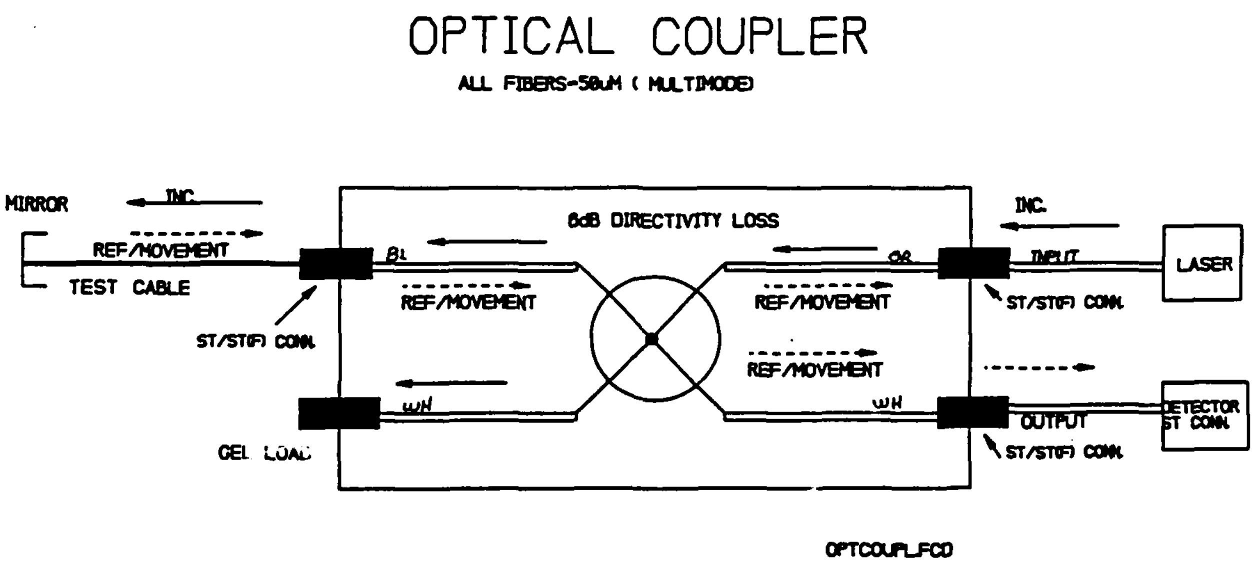
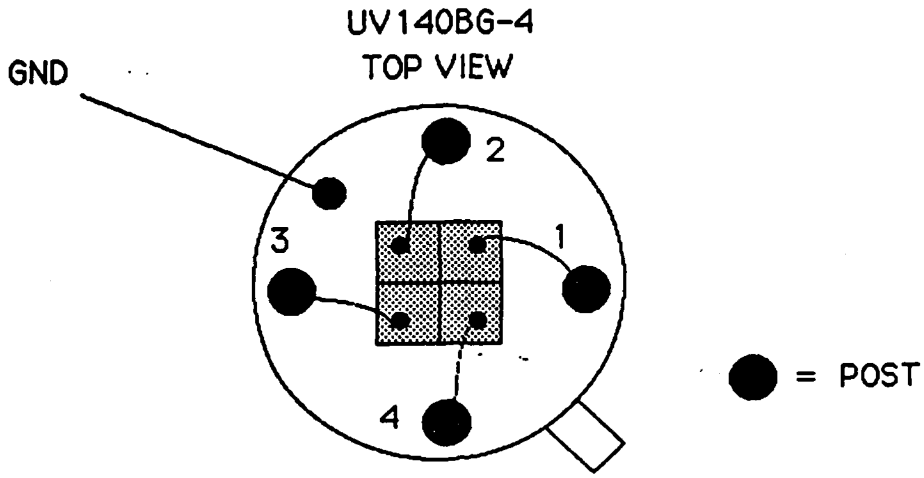
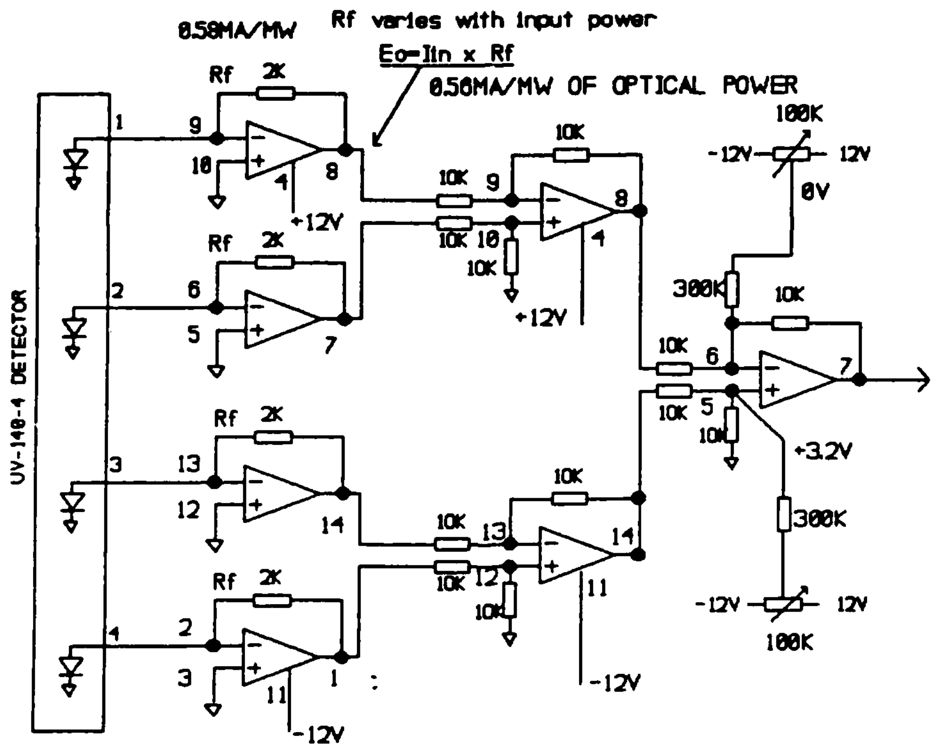



**Figure 3-9. Optical coupler, test set-up.**




**(a) UV 140BG-4 pin to chip connection.**




**(b) OP-amplifiers are TL084ACN (14 pin dip).**

**Figure 3-10. Four quadrant detector layout.**

## 3.5 THE USE OF FIBER REDUNDANCY FOR FALSE ALARMS REDUCTION.

Consider the FIBLOC cable shown in Figure 3-11. If the shaded sector is violated by an intruder, then indicators on A, B, and C would light: not D, E, F,... Now consider the use of the inverter and AND networks shown in Figure 3-12. Cables B, C, and D are sampled to investigate a possible intruder on line C. For an alarm to occur, we require that AND network #3 have all "1"s. For this to occur, the following events are required:

(1) C exhibits a "1"
(2) B and C exhibit a "1"
(3) C and "not" D exhibit a "1".

Each sector is protected by this series of AND networks to reduce the possibility of a false alarm to a negligible level. Three proximal fibers are sampled to investigate a reported intrusion in each sector.

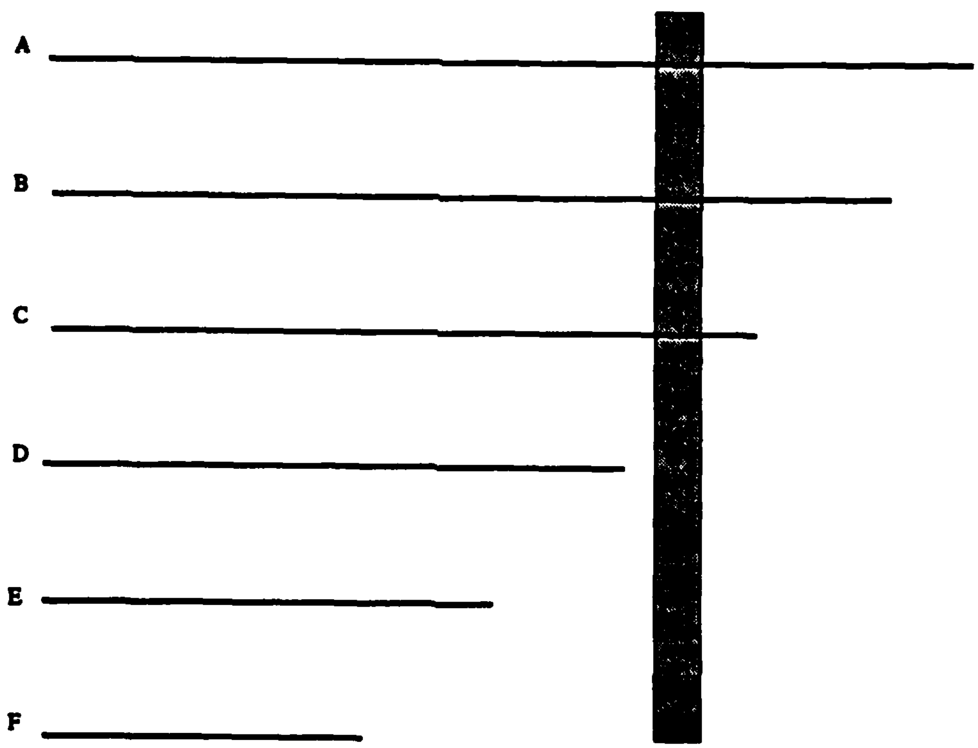



**Figure 3-11. FIBLOC configuration.**

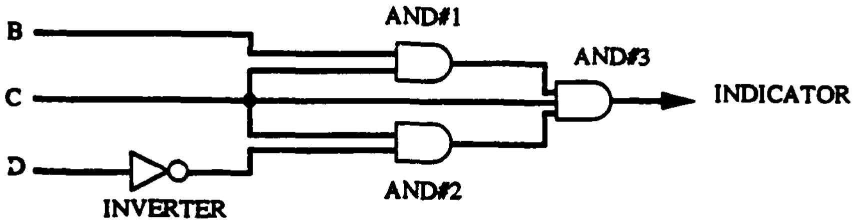



**Figure 3-12. Logic.**

## 3.6 SUGGESTIONS FOR FUTURE IMPROVEMENTS.

The use of low-cost laser sources for each fiber line which incorporate an isolator requires more investigation. Currently, such a device in an assembly is used in a compact disc player at a total cost of $90 each. The power level of these devices are about 10 dB below our current levels. Both ANRO and OPTECH are investigating the cost of increasing the power levels of their current assembly.

The feasibility model demonstrated in May 1993 at Hanscom Field incorporated only the ANDing of two fibers. Future units should include the three line false alarm reductor circuitry recommended in 3.5.

## 3.7 THE INTEGRATED FIBLOC ELECTRONICS.

A photograph of the FIBLOC breadboard system is shown in Figure 3-13. The electronics are placed in four modules as shown placed on a bench above a reel which contains the 100 meter length of fiber; when the 100 meter length of fiber cable is placed on the reel it virtually fills the drum. Five of the fibers are cut within 10 meter lengths.

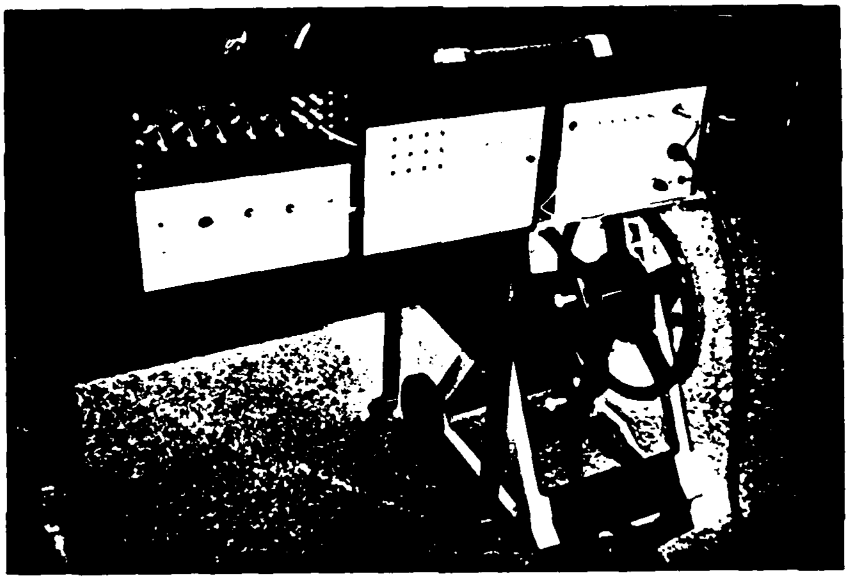


**Figure 3-13. Experimental FIBLOC system.**

The 10 x 8 x 8 inch module located directly above the reel contains the laser diodes, detectors, and preamplifiers. BNC connectors are mounted on the front panel as test points. The middle 10 x 8 x 8 inch module contains the electronic logic and indicators. For target identification, the red, amber, and green lights indicate the presence of a crawler, walker, and runner/vehicle, respectively in each fiber. Separate toggle switches are provided on the right of this module to deactivate the sonic alarms; a reset switch for all the logic is mounted below the toggle switches.

The two modules on the extreme left in Figure 3-13 contain the power supplies and the amplifiers/filters, respectively; the power supply is located in the 10 x 4 x 8 inch module on the bottom. The gain of each amplifier can be adjusted by the front panel potentiometers; the optimum gain is set once for a given installation. A series of indicators above the potentiometers indicates the location of the intrusion.

Each module except for the power supply chassis weighs about 3 pounds in its present form. The power supply weighs about 5 pounds. The finalized design would not contain front panel test points and would be significantly more compact.

# SECTION 4

# HARDWARE DESCRIPTION AND EXPERIMENTAL RESULTS

## 4.1 CHARACTERIZATION OF THE FIBLOC INTRUSION DETECTION SYSTEM.

This section of the report presents the results of experimental studies of a FIBLOC sensor cable (with associated optics and electronics) and employs them to develop a projection of the likely characteristics of a production level FIBLOC Intrusion System.

## 4.2 EXPERIMENTAL HARDWARE DESCRIPTION.

The experimental FIBLOC cable consists of a bundle of 26 single mode optical fibers encased in waterproof plastic tubing. The one half inch diameter cable is flexible with a minimum bend radius of about three inches. Five of the fibers were folded back to form loops, each at a different length. Another five fibers were cut at the same lengths as the loops and terminated with a reflective surface. The remaining fibers were not altered or used.

Five laser diodes, oscillating at a wavelength of 0.83 microns, were used to simultaneously excite five of the fibers. The tests discussed herein simultaneously employed two loops and three mirror terminated fibers. The laser outputs were applied to the input ends of the loop fibers and the output ends of the loops were applied to detector circuits. The mirror terminated fibers were excited through directional couplers. Laser outputs were applied to the input coupler ports while the direct output ports were connected to the fibers. Waves reflected from the fiber terminations are applied to the detectors via the couplers backward wave output ports.

The five detector output circuits are each AC coupled to a preamp. DC drift is eliminated while signal frequencies down to 1 Hz are efficiently coupled to baseband amplifiers cutting off at 400 Hz. Typical amplifier input (CH1) and output (CH2) voltages are shown (measured with a x10 probe) in Figure 4-1. The voltage gains of the amplifiers, as measured from the waveform samples in Figure 4-1, are about 60, that is 35 dB.

The amplifier output signals were viewed using a Gould 1425 digital storage oscilloscope: and, they were recorded using a Gould 6120 plotter.

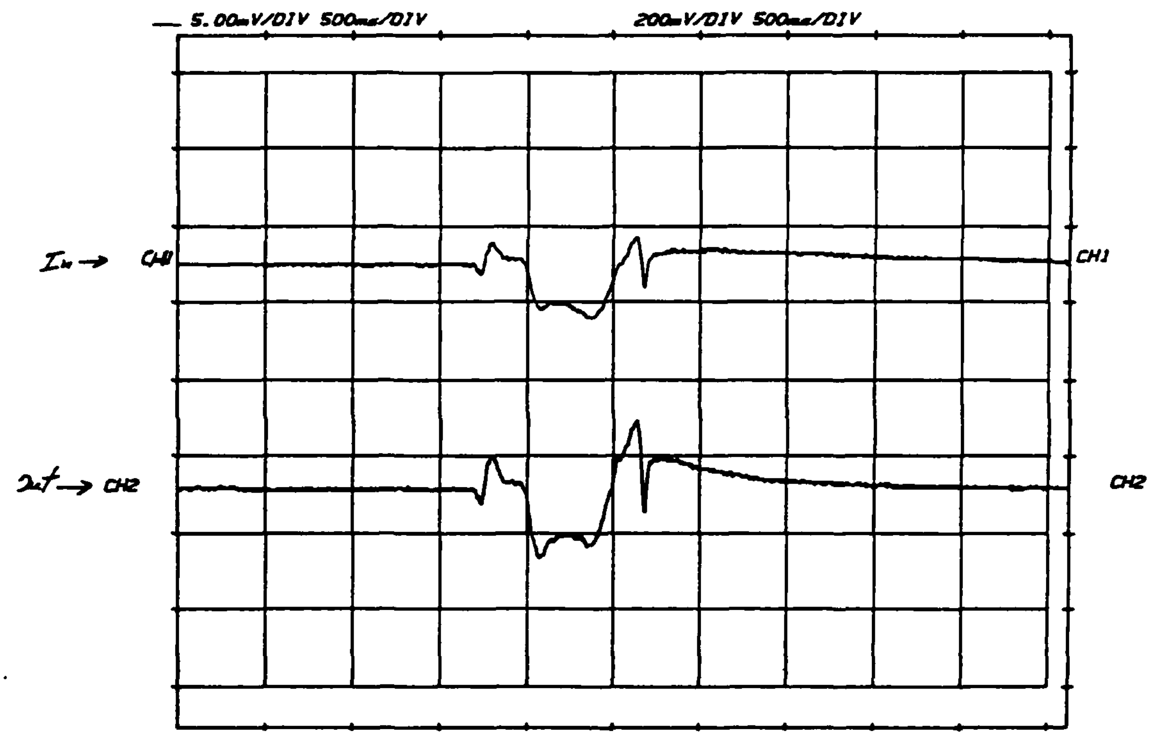



**Figure 4-1. Amplifier input & output voltage waveforms (x10 probe).**

## 4.3 EXPERIMENTAL SENSOR MEASUREMENTS.

The FIBLOC sensor described above was tested in both indoor and outdoor settings. For indoor testing the cable was sandwiched between two 3/4 inch pieces of foam rubber and taped to a piece of plywood and placed on the floor. This arrangement reduced incidental cable movement to a negligible level. The outdoor tests were performed with about a 6 foot section buried under a couple of inches of loose dirt and the remaining cable simply resting on grass.

The cable sensor was tested by applying pressure disturbances to the cable in different ways. Each disturbance was repeated five times and the waveform produced on a different one of the five fiber outputs was measured and recorded each time. For each type of disturbance described below, five waveforms, one for each of the laser excited fibers, was recorded. Fibers 1 and 2 were looped fibers while fibers 3, 4 and 5 were mirror terminated fibers.

The tests results presented are:

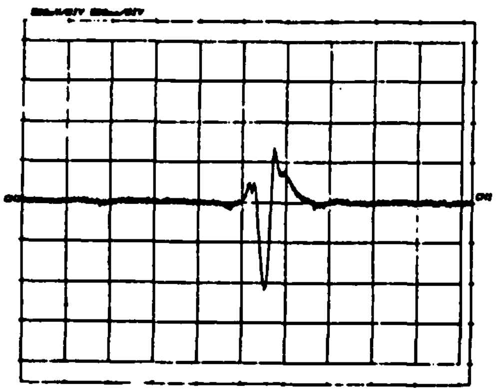
| INDOOR | OUTDOOR |
|---|---|
| • Wheelbarrow | • Human Step Buried |
| • Human Step | • Human Step on Grass |
| • Human Crawl | |

### 4.3.1 Indoor Test Results.

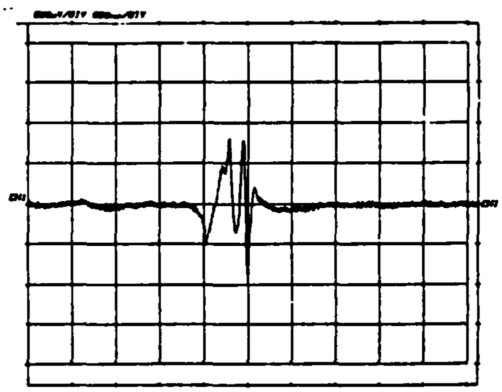
The first indoor tests consisted of pushing a 25 pound wheelbarrow, with a three inch wide wheel, across the cable sandwich. This test provided the greatest consistency, in terms of repeatability of the disturbance. The waveforms generated at the fiber outputs are presented in Figure 4-2. The waveform at the output of fiber 1 is presented in Figure 4-2 (a), fiber two output is in Figure 4-2 (b), etc..

The second set of test results are shown in Figures 4-3 (a) thru 4-3 (e), which record the waveforms generated by a 190 lb. human male taking a normal walking step onto and across the fiber.

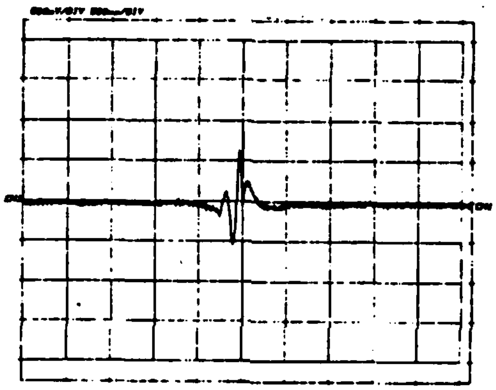
Figures 4-4 (a) thru 4-4 (e) record the waveforms generated by a human taking a normal crawling motion across the fiber.



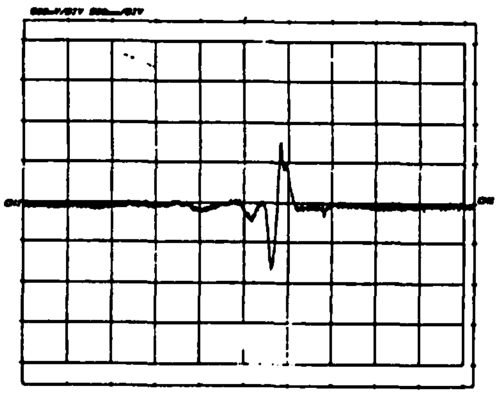
(a) Fiber #1.



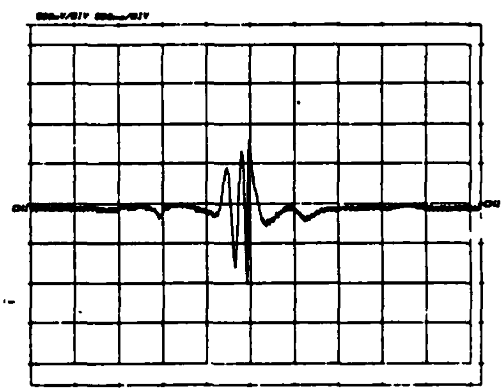
(b) Fiber #2.



(c) Fiber #3.

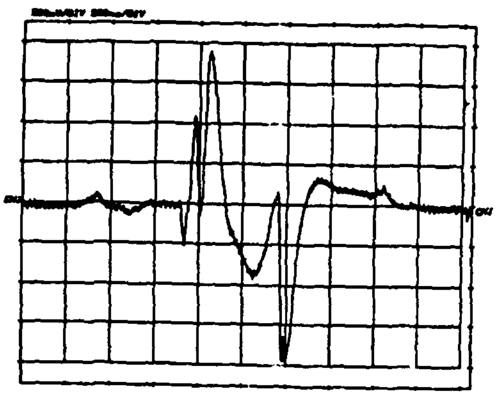


(d) Fiber #4.

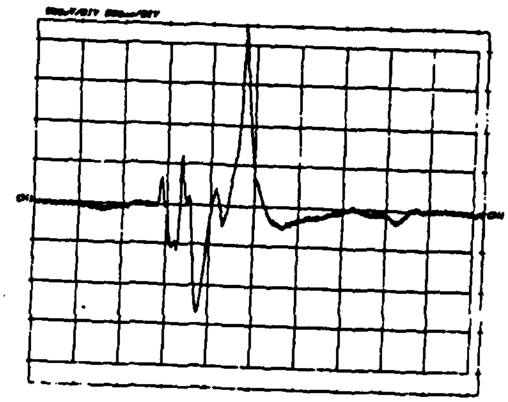


(e) Fiber #5.

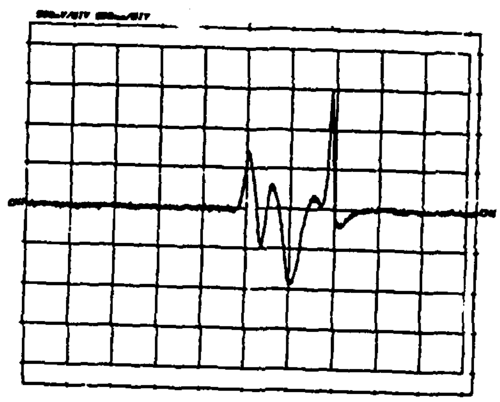
**Figure 4-2. Indoor wheelbarrow waveforms.**



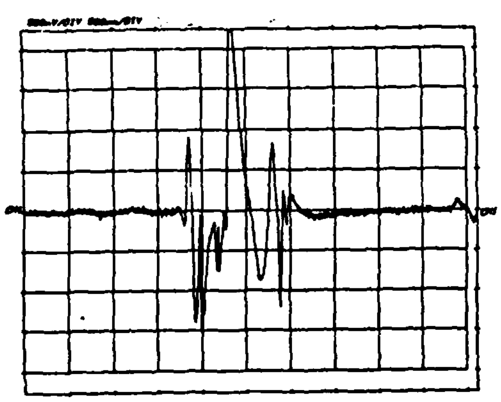
**(a) Fiber #1.**



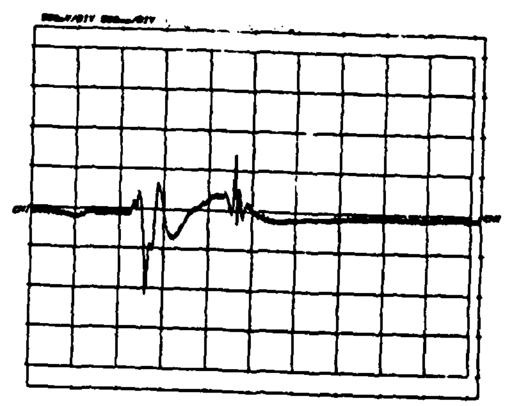
**(b) Fiber #2.**



**(c) Fiber #3.**

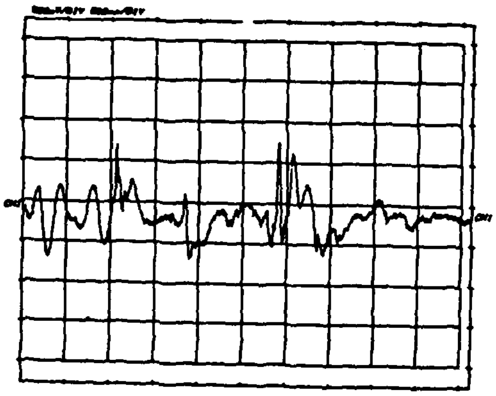


**(d) Fiber #4.**

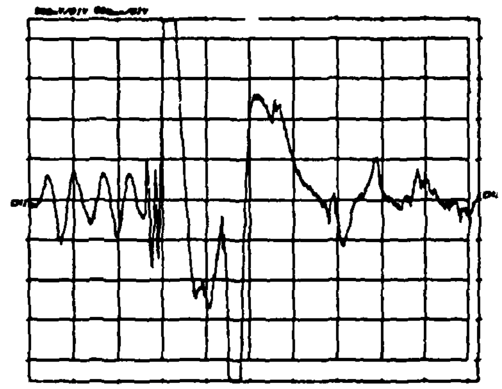


**(e) Fiber #5.**

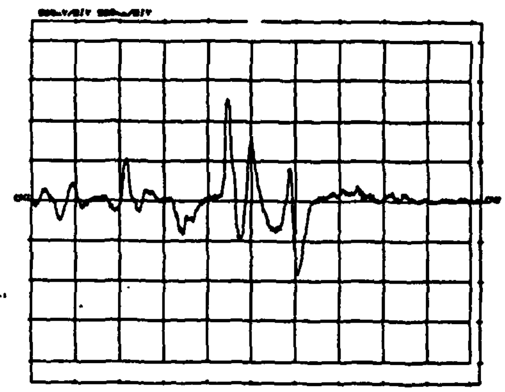
**Figure 4-3. Indoor human step waveforms.**



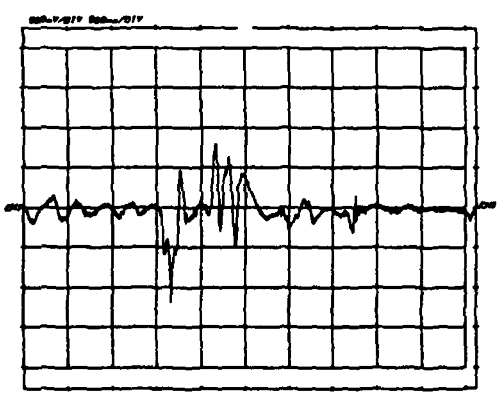
(a) Fiber #1.



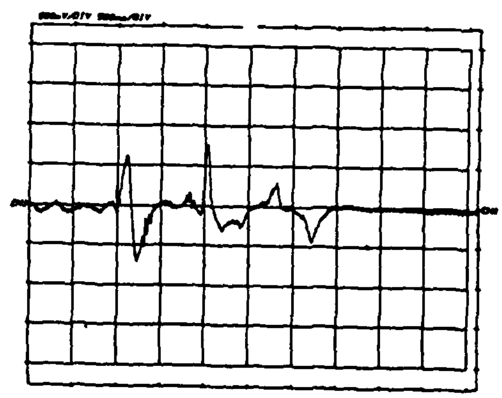
(b) Fiber #2.



(c) Fiber #3.



(d) Fiber #4.



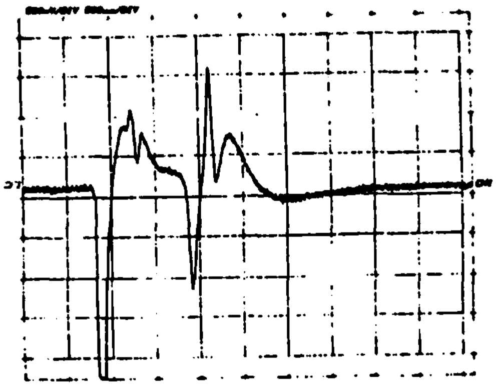
(e) Fiber #5.

**Figure 4-4. Indoor human crawling waveforms.**

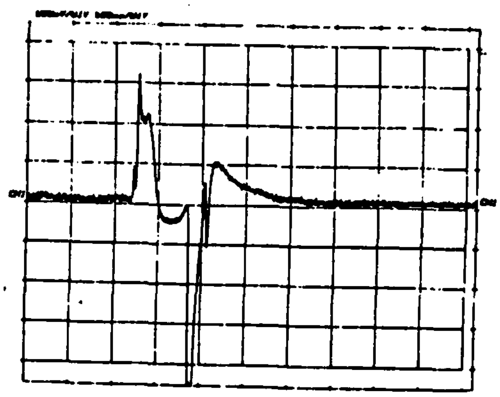
### 4.3.2 Outdoor Test Results.

The first set of outdoor test results are shown in Figure 4-5 (a) thru 4-5 (e). These waveforms were generated by a human walking onto and across a section of the cable that had been placed in a shallow trench and buried with a couple of inches of dry (not packed) dirt.

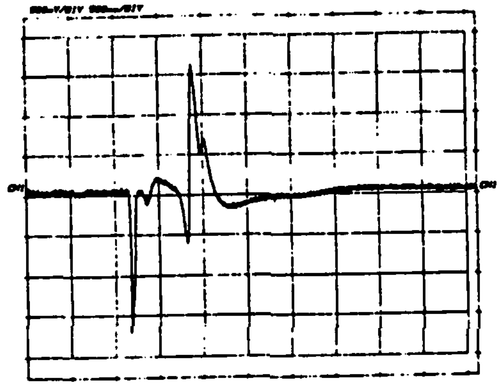
Figures 4-6 (a) thru 4-6 (e) are the waveforms generated by walking onto and across sections of the fiber that were laying flat on the grass surface.



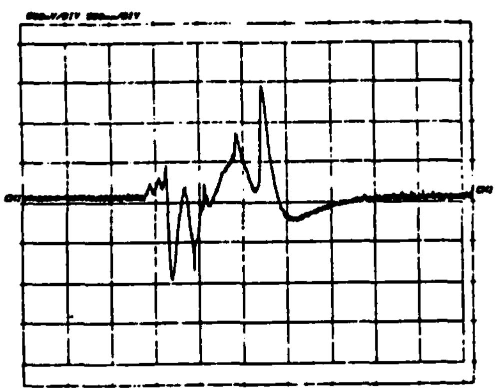
**(a) Fiber #1.**



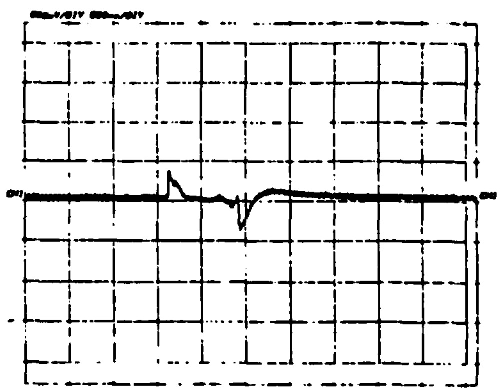
**(b) Fiber #2.**



**(c) Fiber #3.**

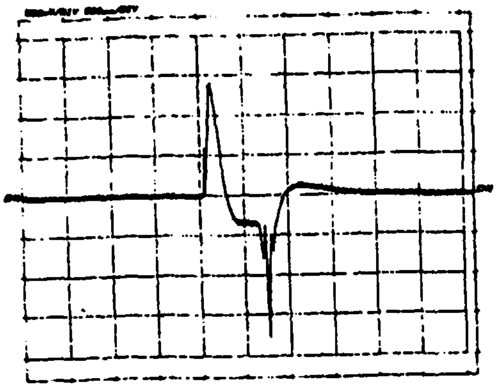


**(d) Fiber #4.**

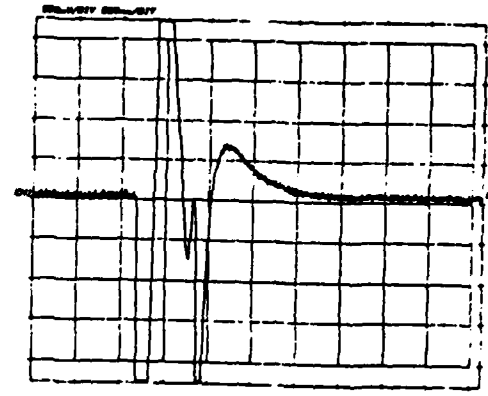


**(e) Fiber #5.**

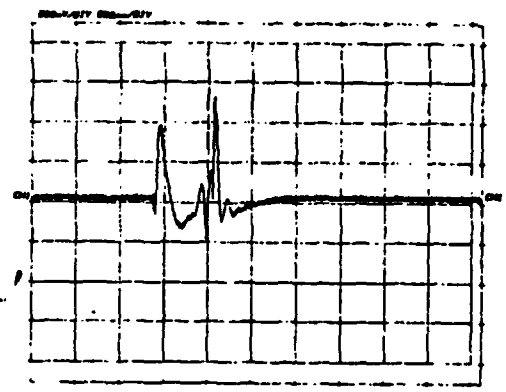
**Figure 4-5. Outdoor buried human step.**



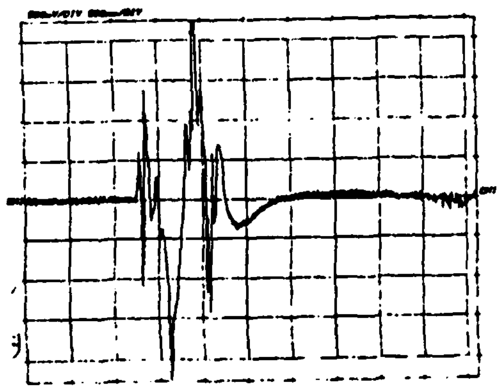
(a) Fiber #1.



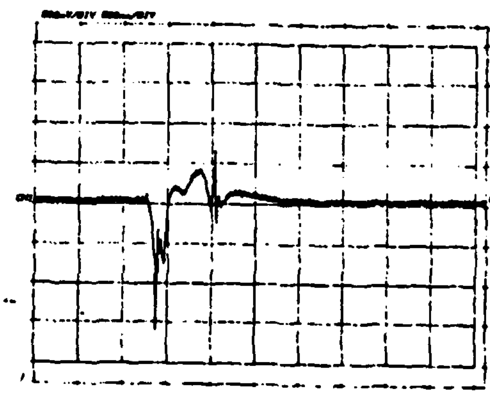
(b) Fiber #2.



(c) Fiber #3.



(d) Fiber #4.



(e) Fiber #5.

**Figure 4-6. Outdoor grass surface - human step.**

## 4.4 DISCUSSION OF RESULTS.

The waveforms shown above are generated when the fiber bundle is disturbed. The greater the disturbance, the larger the voltage. Minimum detectable signal levels are limited (in this experimental hardware) by 60 Hz pickup on the front end of the amplifiers and random noise at frequencies out to 500 Hz. A sample of this background disturbance is shown in Figure 4-7 where a total peak to peak voltage of 80 mv is observed with about 10 mv of the total due to noise and the remainder due to 60 Hz pickup. The minimum signal voltage in the measurements presented above is greater than one volt peak to peak. Clearly, background levels are more than an order of magnitude below the smallest signal levels and are not a problem relative to detecting the type of disturbances produced during these tests. 60 Hz pickup was significantly reduced in the revised logic circuitry by reducing the input impedance of the preamplifier by order of magnitude.

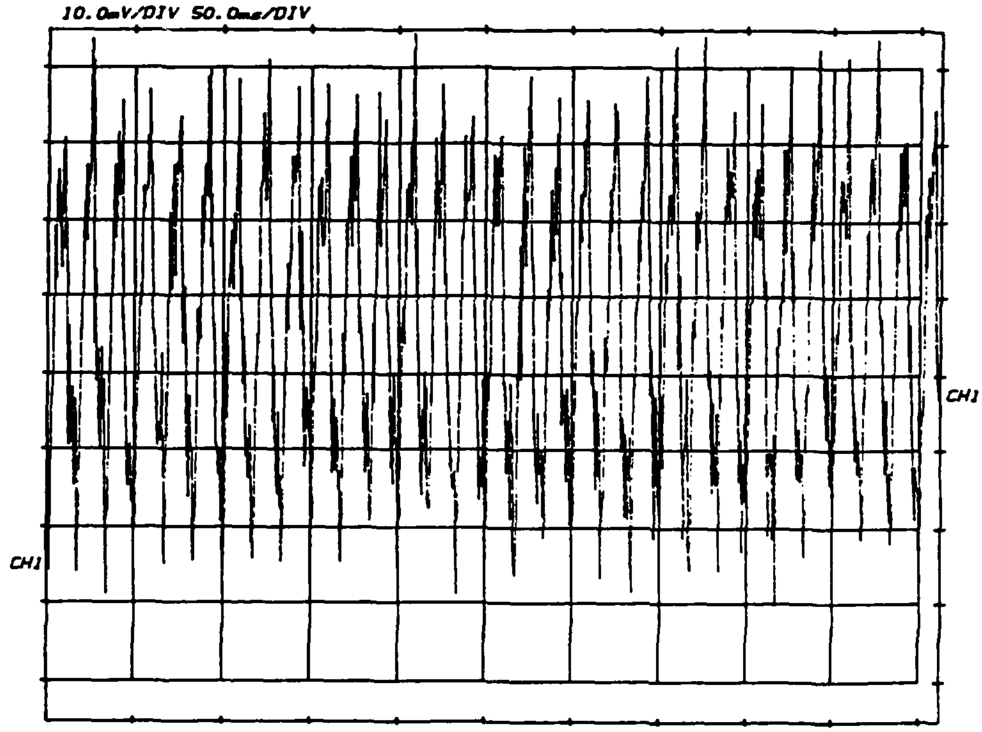



**Figure 4-7. Amplifier 60 Hz pickup plus random noise.**

It must be noted however that very slight cable motion, which produces only a few millivolt output voltage waveform can also be detected, if it is desirable to do so, since the maximum sensor signal frequencies are less than 10 Hz. Clearly, the signal bandwidths of the amplifiers

can be reduced to as low as 10 Hz without impacting the higher frequency signal waveforms if these movements are to be detected. To eliminate the response to slight cable movement maintaining the low frequency cut-off at 15.9 Hz is efficient.

The durations of the signal waveforms are a direct function of the amount of time the disturbance remains on the cable. The waveform begins when the foot first comes down on the cable. If the foot stays on the cable the voltage will reduce to zero and not rise again until the foot is removed. *Observation of many waveforms lead to the conclusion that these waveform durations measure the length of time that the cable is being disturbed.*

Other than duration, the waveform shapes and amplitudes under any given disturbance situation depends more on conditions concerning the *position of the fiber in the bundle* than it does on the specific external disturbance. *In other words, waveform shape, except for duration, will not provide many discrimination features.* It should be mentioned that enhanced discrimination capability can be anticipated in a total system embodiment because multiple cables will be employed in high probability of detection perimeter protection applications.

## 4.5 SYSTEM APPLICATION CONCEPTS.

The following two subsections develop an intrusion detection system concept that can be used as a baseline. Variations can be made as more specific site data and protection problem details are obtained.

### 4.5.1 Low Sensitivity, Low False Alarm Rate, High-Cost Approach.

The following discussion assumes an intruder is an average male (5′-9″ height with a foot print of 1.0′ and the average center to center distance between walking and running steps of 2.5′ and 3.75′ respectively. To create a perimeter intrusion detection zone with a near unity probability of detection a surface area of about 4′ must be covered, with cables spaced less than 1′ apart. For this discussion, six FIBLOC cables, spaced apart by ten inches will be used but five cables spaced apart by 1′ would probably suffice. This assumes that an intruder does not suspect that the intrusion detection system is present, and could possibly avoid detection by vaulting over the zone; otherwise, a wider detection zone could be created.

It is further assumed that waterproof cables containing 26 optical fibers are available in any necessary length and that the fibers will all be terminated with a near perfect reflecting surface at appropriate distances from the sources. The distance between fiber terminations will

determine intrusion location resolution. For example, protection of a 200 meter perimeter with 26 fiber cables will provide resolution of about 8 meters (200/26 = 7.69 m). To increase resolution to about 4 meters then we need to increase the number of fibers per cable to 52 or employ two parallel, staggered 26 fiber cables to cover the perimeter.

Assume then that 4 meter resolution is required and 52 optical fibers per cable are available. With six cables to cover the required 4′ surface the total number of signal channels can exceed 300.

The issue, at this point, is to determine whether each fiber should be an individual parallel channel or whether a single laser diode can power all 52 or at least some fraction of the 52 fibers per cable. A similar question pertains to the detection and amplifier circuits for each fiber. The key here is that the signal waveforms vary so slowly so that time division multiplexing of all three hundred fiber output signals is relatively straight forward. Also, digital processing of the resulting signal stream is easily carried out in real time using commercially available PC's. Under the assumption that 300 or more fiber channels are useful, the base case system will assume a dedicated detector per fiber but that the post detection circuits will be shared via a multiplexed signal set (either time domain modulation (TDM) or frequency domain modulation (FDM) or a combination of both).

Given that six cables are available for the perimeter, the number and locations of fibers that are disturbed along with the time history of the waveforms caused by the disturbances contain discrimination information. It is safe to assume that if the application demands a high level of discrimination between humans, animals and machines that might cross the perimeter, then the use of a large number of fibers coupled with relatively low bandwidth digital processing can provide discrimination on the basis of size and motion characteristics during the act of intrusion. In other words, the sensor can be configured and the resulting signals analyzed to allow location and rate resolution so fine as to allow maximum reduction of nuisance alarms.

A major advantage of the FIBLOC intrusion sensor cable is that is can be engineered into a total system configuration at any level desired. At one extreme 5 cables with only one source, detector and amplifier per cable detects an intrusion with near unit probability of detection. The capability of the system can be gradually upgraded by exciting and monitoring more fibers in a cable. The processing can be minimal, based only on location of the intrusion or it can be

expanded to many fiber excitation, and digital processing of the resulting high resolution waveforms patterns. The system concepts (and associated costs) are readily scaled to a wide variation of application requirements.

### 4.5.2 High Sensitivity, Low-Cost Approach.

A recent paper published by investigators from China show how a multimode fiber cable similar to that used by FIBLOC can be excited by a HeNe laser to achieve high sensitivity.[2] The cable is buried about six inches below the surface in two different configurations and gain settings. The system, however, is susceptible to high false alarms. The results for a walker passing over two different sensitivity fibers is shown in Figure 4-8. The response for a walker, crawler, and runner for the low sensitivity configuration is presented in Figure 4-9. It is clear from both figures that a detection can occur ± 1 meter from the fiber for the worst case with only a 3 dB change in the S/N ratio.

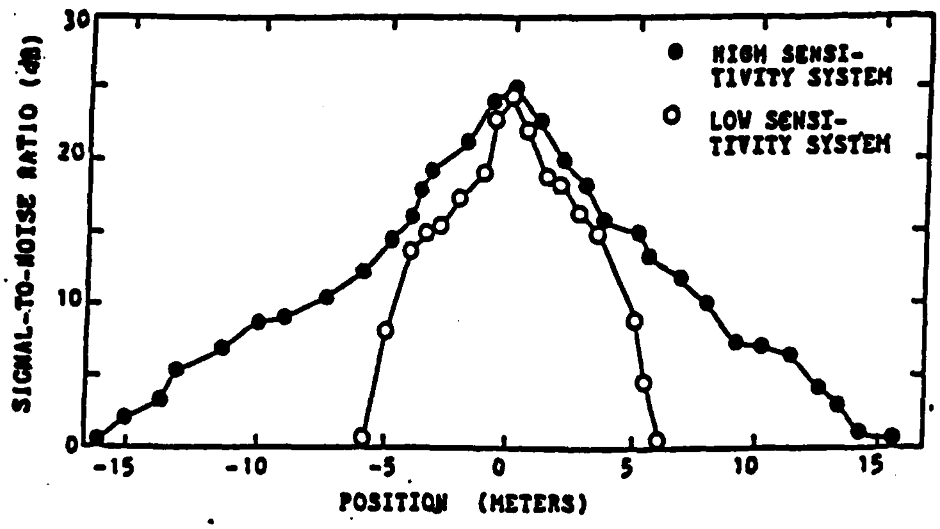



**Figure 4-8. S/N vs. distance from cable for a walker using the low and high sensitivity configuration.**

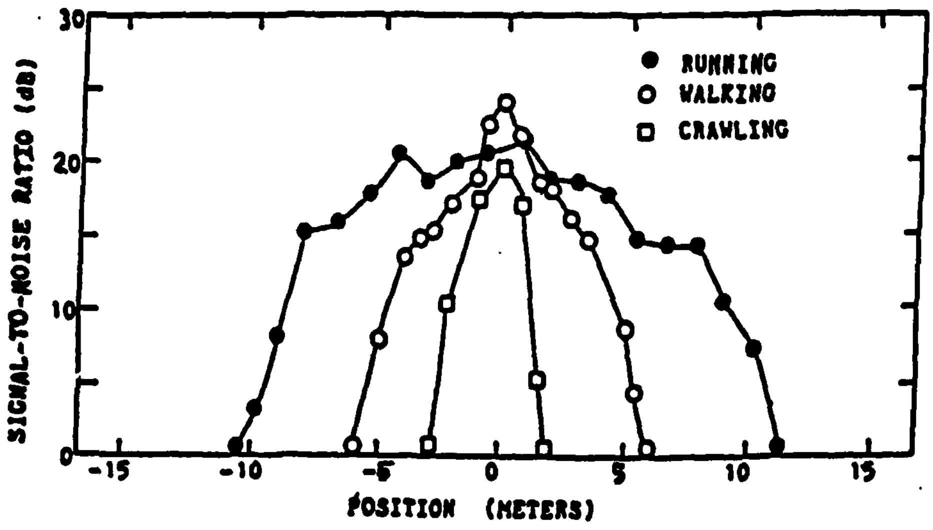



**Figure 4-9. S/N vs. distance from cable for running, walking and crawling for the low sensitivity configuration.**

The results of the paper were verified in the test demonstration at Hanscom Field using a single fiber with auxiliary electronics. False alarms can be controlled in the FIBLOC configuration using the AND networks as described in Section 3.5. The increased gain over the present FIBLOC configuration required for a detection range of ± 1 meter was measured to be 30 dB. What is important about using increased gain together with the FIBLOC redundancy technique to reduce false alarms is that only one fiber bundle instead of five is required resulting in a considerable cost saving. Based upon experiments, it is estimated that a single FIBLOC bundle of fibers can be used to protect a perimeter with a ± 1 meter protection band for less than $9/foot. The Chinese investigators use a zero-crossing scheme for discrimination which we found to be unreliable.

## SECTION 5

## MODES OF DEPLOYMENT: PROJECTIONS

### 5.1 PROBABILITY OF DETECTING AN INTRUDER USING A FIVE CABLE LOW-GAIN SYSTEM.

For purposes of this projection it is assumed that a suitable pressure sensitive, environmentally tested (waterproof) cable, such as the section employed in the demonstration, containing 26 or more multimode graded index fibers, is available in any required lengths. The individual fibers of the cable are terminated by essentially perfectly reflecting mirrors at intervals which fix the spatial resolution of a single cable. The probability of detection as well as the expected resolution will be enhanced by deploying several cables in parallel as shown in Figure 5-1. In particular, the design spatial resolution of the individual cable is enhanced by staggering the resolution cells of parallel cables (indicated by ticks on the parallel lines on Figure 5-1). Analysis shows that four FIBLOC cables placed approximately 0.9 normalized footprints apart would yield a better than 90% probability of detection of a walking intruder; a crawling or vehicular intruder is detected with essentially unit probability.

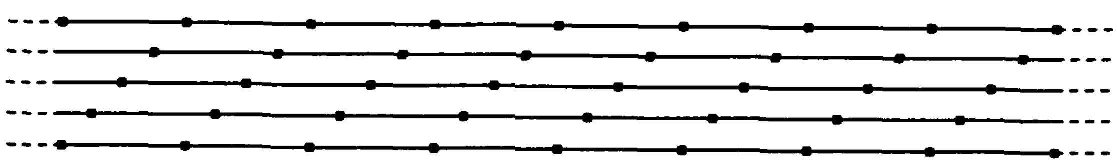


**Figure 5-1. Parallel deployment, staggered sensor segments.**

For the purpose of a general assessment of the likelihood of intruder detection, we pose some generalized application scenarios. We may distinguish two modalities for a potential intruder:

1. a crawling or vehicle-borne intruder
2. a pedestrian, walking or running intruder.

The essential difference between these two intrusion modalities is that (1.) maintains continuous ground contact while in the case of modality (2.) the ground contact is discretized or intermittent. FIBLOC cables deployed in parallel, as described above, will evidently detect intruders of the first class with essentially unit probability and resolution cell corresponding to

that of a single cable divided by the number of cables deployed (independent of the lateral spacing of the parallel cables). The second, discrete, modality of intrusion necessitates a more elaborate analysis.

A lower estimate of the probability of a single FIBLOC cable alarm may be derived from a classical result in the theory of probability, Buffon's problem.

Consider a series of parallel cables deployed a distance H apart. Assume that the intruder has a single heel-to-toe footprint of length F. Further assume that the intruder, unaware of the precise situation of the FIBLOC cable (or his ultimate objective) proceeds to traverse the parallel cables at a random angle, Figure 5-2. Then, in terms of the normalized spacing h = H/F, the probability, p, of an alarm resulting from any single footprint is given by[3]

$$p = \frac{2}{\pi}\frac{1}{h}, h \geq 1;$$

$$= \frac{2}{\pi}\left\{\frac{1}{h}[1 - \sin(arccos\ h)] + arccos\ h\right\}, h \leq 1.$$

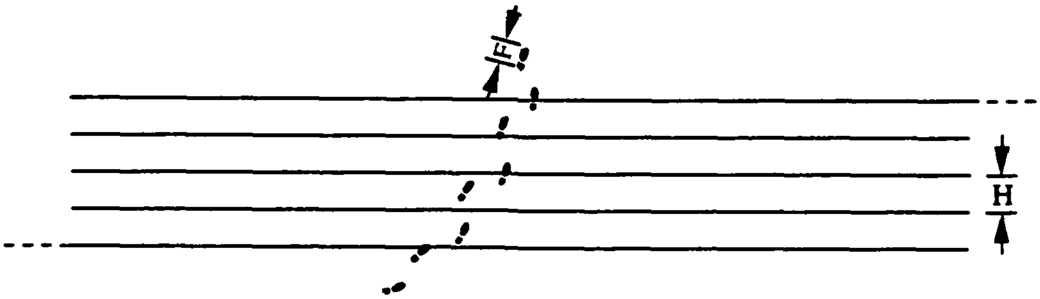



**Figure 5-2. Walking intruder schematic.**

Particular values are recorded in Table 5-1. These values are interpreted as low estimates because they are based on a random orientation of the foot with respect to the cables. An intruder crossing the cables in the direction of the protected interior objective is most likely to traverse the cable along a path nearly at right angles to the parallel cables. A single footprint placed in a fashion naturally associated with such a path will produce an alarm with nearly unit probability. On the other hand, a poorly oriented intruder (who might in the worst case traverse the deployed parallel cables along a path nearly parallel to the cables) would have a relatively

low probability of producing an alarm with a single nearly parallel footprint. However, the path of such an intruder is such as to involve multiple footprints within the band of FIBLOC cable deployment.

**Table 5-1. Probability of Detection of a single footprint for Normalized Spacing of Sensor Cables.**

| h | p |
|---|---|
| 0.50 | 0.83724842 |
| 0.60 | 0.80254106 |
| 0.70 | 0.76634136 |
| 0.80 | 0.72797542 |
| 0.90 | 0.68615886 |
| 1.00 | 0.63661977 |
| 1.10 | 0.57874524 |
| 1.20 | 0.53951647 |
| 1.25 | 0.509295820 |

The probability of at least one alarm due to a multiplicity of N footprints is

$$p_n = 1 - (1 - p)^N.$$

Particular values are listed in Table 5-2.

**Table 5-2. Probability of Detection of multiple footprints.**

| h | p | -------------------N-------------------- | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| 0.8 | 0.7280 | .7280 | .9260 | .9799 | .9945 |
| 0.9 | 0.6862 | .6862 | .9051 | .9691 | .9903 |
| 1.0 | 0.6366 | .6366 | .8680 | .9520 | .9826 |

In summary, it may be estimated that four FIBLOC cables placed approximately 0.9 normalized footprints apart would yield a better than 90% probability of detection of a walking intruder. Further calculation may confirm that a particular situation requires an enhanced capability which can readily be achieved with more and/or more closely spaced cables.

## 5.2 ESTIMATED RANGE (PERIMETER OF PROTECTED PRECINCTS) FOR FIBLOC.

The linear range or maximal perimeter of the precincts to be protected by a FIBLOC sensor are limited by a relatively sophisticated aspect of the characteristics governing propagation of light in a multimode graded index fiber. Since the FIBLOC system is essentially a cw system with minuscule 10-20 Hz bandwidth requirements, fiber bandwidth and dispersion do not limit the system. Furthermore, it emerges from the estimated FIBLOC characteristics based on experiments conducted at ANRO's Rochester, N.Y. facilities described in Section 4, that "the signal bandwidth of the amplifiers can be reduced to 10 Hz without impacting the signal waveforms while pickup and noise levels visible now will be completely eliminated. This noise reduction will then allow a significant reduction in the minimum detectable signal. It is reasonable to assume that it will be in the microvolt range." With 10 mw of available power and a specified attenuation of < 3 db/km for a total of -30 dB m; it seems clear that 5 km linear range (10 km round trip) is not ruled out on the basis of detectable power.[4] There remains the fact that detection of a disturbance by the FIBLOC system depends on the change induced by the disturbance in the distribution of light among the four quadrants of the detector surface.

Fundamentally, a systematic variation in intensity over a transverse plane corresponds to a systematic distribution of amplitudes and phases among the propagating modes in the optical fiber. Assuming an initial distribution corresponding to an initial *non-uniform* distribution (e.g., most light concentrated in first quadrant) the output distribution must be some deterministically related non-uniform distribution, a change in which (produced by some disturbance somewhere along the fiber path) constitutes the signal to be detected. Due to differential attenuation of the fiber modes and various random (but statistically position independent distribution of) intermodal coupling effects, after propagation through a sufficient length of fiber: "The modal power distribution at the output is independent of the modal power distribution at the input. The equilibrium condition is achieved beyond a certain propagation distance called the equilibrium length. Steady state appears to be reached after about 2 km."[5] Clearly this equilibrium length depends upon the particular cable and more broadly on the current state of fiber technology. The equilibrium length would be expected to increase with decrease in fiber attenuation. The particular estimate cited was obtained from observations on fiber with attenuation of 5.1 dB/km. Thus the FIBLOC cable might well have an appreciably longer equilibrium length. However, in the absence of definitive data for particular fiber cable a value of 4 km would appear to be a reasonable conservative estimate.

## 5.3 A LOW-COST SINGLE BUNDLE FIBLOC SENSOR EMPLOYING HIGH GAIN - LOW FALSE ALARM APPROACH.

The system described in 4.5.2 was evaluated just at the conclusion of the 2 year Phase II investigation. Unfortunately, there was insufficient time to calculate the expected false alarm rate for a single fiber bundle FIBLOC type system. Qualitatively, the false alarm rate can be made arbitrarily low, however, by ANDing more cables in the FIBLOC bundle (see Section 3.5). By using a single cable system the effective detection band can be extended readily to ± 1 meter corresponding to the coverage provided by using the five cable installation described in 5.1. The result is a sensor system at a cost of $8.90/foot which includes a charge of $2/foot for ground preparation. For the FIBLOC installation, a simple narrow 4 - 6 inch deep trench cut in a straight line is required.

Another approach suggested by the recent experiments using high gain for extended band coverage, concerns an effective means for using fiber optic perimeter under frozen ground conditions. The concept would employ a variable gain amplifier where the gain would be a function of temperature. For frozen ground (e.g., -20°F), the gain would be set to its maximum level. The absolute gain at this temperature would be set by a constant false alarm rate (CFAR) closed loop.

A thermocouple or equivalent voltage vs. temperature transducer would then decrease the gain so that, for example, at greater than 40°F, the gain would be about 30 dB above that of the present FIBLOC system.

## SECTION 6

## CONCLUSIONS AND RECOMMENDATIONS

The intrusion detection scheme FIBLOC was conceived by Dr. Walter K. Kahn and was described by him in U.S. Patent 4,931,771 issued June 5, 1990. The trademark, FIBLOC, was allowed to ANRO Engineering, Inc., December 3, 1991. Copies of these documents are contained in Appendix D. The physical basis of the FIBLOC sensor rests on the (phase) sensitive interference phenomena in the propagation of an off-axis coherent optical/infra-red beam through a graded index fiber. Because the system senses dynamic changes in its environment, it is ready to detect sequential independent intrusions separated in time by seconds. The FIBLOC cable contains a multiplicity of fibers loops (physical loops or optical loops obtained with mirrored end fibers) of different lengths. This length difference defines the intruder localization zones. The individual zones are, separately or in combination, connected via a data processing unit to alarm indicator (lights). The partition between illuminated and dark sets of lights fix the sensor segment or localization zone over which the intrusion has taken place. In an operational configuration, a map display could be used to pinpoint an intrusion event.

Identification of the type of intruder is made by the relatively inexpensive processor unit. This unit provides intruder discrimination with adjustable threshold for automated detection with a low false alarm rate. The information content of the signals generated in this system provides a basis for intruder classification. Field tests of the FIBLOC sensor performed at ANRO's field laboratory in Rochester, N.Y., showed that a dominant signature characteristic of various different modes of intrusion was the *duration* of the signal disturbance; on the other hand, the same sort of intrusion produced a wide range of spectral data. Accordingly the logic design is based on the duration of the signal. The processor illuminates either a red, amber or a green light to announce an intrusion. In the demonstration unit, a red light (the most dangerous situation) represents a crawler, a green light signifies the probability of a runner or vehicle, while an amber light indicates a possible walker.

False alarms, which constitute a major drawback in other semi- or fully-automated intrusion detection systems, can be reduced by utilization of the generally available redundant indications for a true intrusion from the FIBLOC cable for all but the most distant localization zone. One level of redundancy has been utilized in the final processor configuration as described in Section 3. Further redundancy can readily be employed to significantly reduce the false alarm

rate as described in 3.5. To effect a redundant indication for the most distant zone(s) a special supplemental fiber can be utilized at a small extra cost. The improved sensor was operated for several hours without experiencing any false alarms.

The FIBLOC system design, with individual fibers excited by lasers, does not appear to be limited by available power. The limiting feature, described in Section 5, is to be found in the tendency to mode equilibrium of propagation of many modes in a multimode graded index fiber. Based on this phenomenon, a limit of 2 km linear range is projected. With the FIBLOC processor centrally positioned, a perimeter of 4 km circumference can therefore be encompassed. Using a cable with a longer equilibrium length (lower attenuation/km) can double this range.

The FIBLOC cable could be produced by sputtering mirrors on sections of fiber *before* final assembly of cable, (i.e., before the extrusion of the outer protective jacket). This would eliminate the need to subsequently break the integrity of the outer protective jacket. It would also improve the uniformity of the product.

It is recommended that the individual laser sources be fitted with isolators to maintain stability of oscillation independent of feedback from disturbances on the cable. One candidate low-cost laser source, now employed in the common CD player is being investigated. We are asking the manufacturer to estimate on a higher power version of this source. Such disturbances have been observed to cause lasers to execute spontaneous jumps and noise oscillations possibly triggering false alarms. The present system employs some (dissipative) decoupling and the FIBLOC redundancy feature to suppress false alarms due to this effect.

Four FIBLOC cables deployed 0.9 normalized footprints apart are estimated to yield a greater than 90 percent probability of detection of a walking - running intruder; a crawling or vehicular intruder is detected with essentially unit probability. A much lower cost system has also been demonstrated using only one cable and having the same coverage.

Other fiber optic perimeter protection systems recommend serpentine (meander mode) deployment of fiber cable. This mode of deployment results an actual required length of cable equal to approximately six (6) times the linear length of protected perimeter. See Appendix C. To our knowledge, no theoretical a priori probability estimate of missing an intruder is associated with this meander deployment. This factor is to be compared with the recommended FIBLOC installation described in Section 5.

ANRO recently demonstrated the improved version of the FIBLOC sensor to interested parties in May of 1993. The FIBLOC system is ready for Phase III production configuration for the purposes of the Department of Defense, and is recommended for installation and sale to commercial interests.

# SECTION 7

## REFERENCES


[1] G. F. Ross, (P.I.) et al., "An Optical FIBer Intrusion LOCation Sensor (FIBLOC) for Surface and Subsurface Perimeter Protection," (U) PHASE I Final Report, Contract DNA 001-88-C-0142 to ANRO Engineering, Inc., April 13, 1989, UNCLASSIFIED.

[2] Chung-yee Leung, et al., "Optical Fiber Security System: A Field Test Report," (U) SPIE Vol 838 Fiber Optic and Laser Sensors V (1987)/365-371, UNCLASSIFIED.

[3] J. V. Uspensky, "Introduction to Mathematical Probability", (U) Ch. XI, sec. 14, McBraw Hill Book Co., 1937, UNCLASSIFIED.

[4] C. Yeh, "Handbook of Fiber Optics", (U) Academic Press, 1990, UNCLASSIFIED.

[5] C. E. Chamberlain, et al., "Optical Fiber Characterization Attenuation, Frequency Domain Bandwidth, and Radiation Patterns," (U) NBS Special Publication 637, Volume 2, U.S. National Bureau of Standards, Washington, DC, October 1983, (See Chapter 1, p.5), UNCLASSIFIED.

# APPENDIX A

## DESIGNS FOR FABRICATION OF A SPECIALIZED FIBLOC CABLE

Considerable effort and ingenuity was expended, particularly on the part of ANRO's sub-contractor, OPTECH, to devise efficient means for fabricating a specialized FIBLOC cable from basic constituents such as optical fiber, mechanical strengthening members and protective sheathing materials. Although the ultimate mode of fabrication adopted was involved and modification of a commercial cable (one of the options envisioned in the Phase II proposal) drawings of the projected alternative means for in-house fabrication are included in this Appendix for reference and as a matter of record.

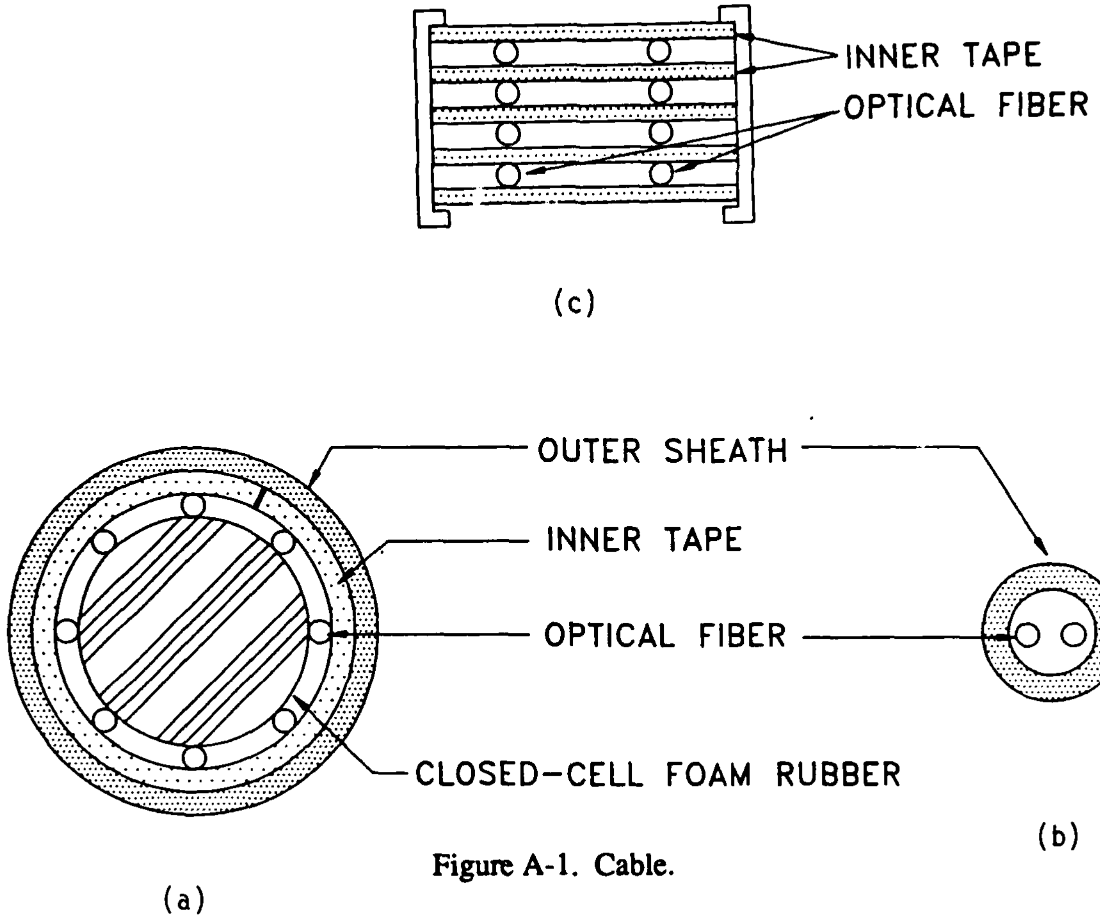



Figure A-1. Cable.

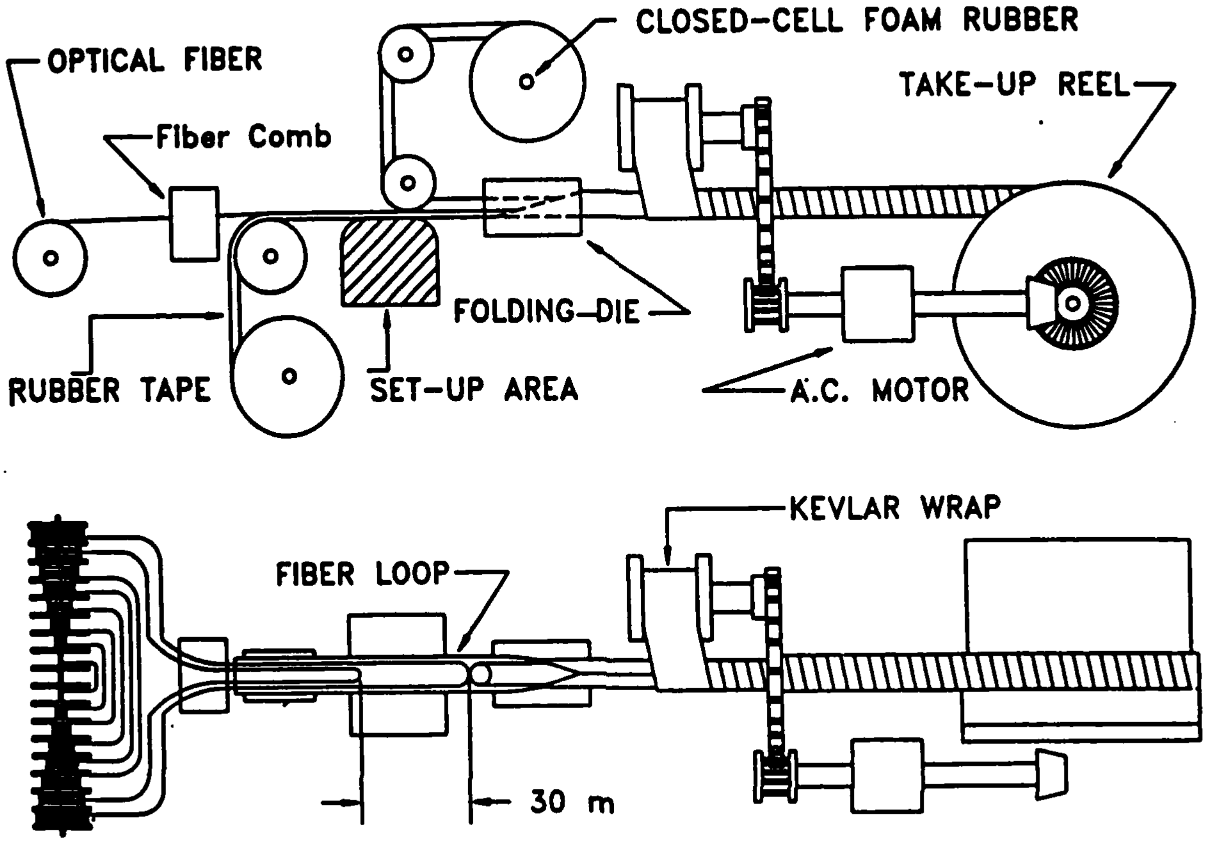



Figure A-2. Sensor manufacturing process.

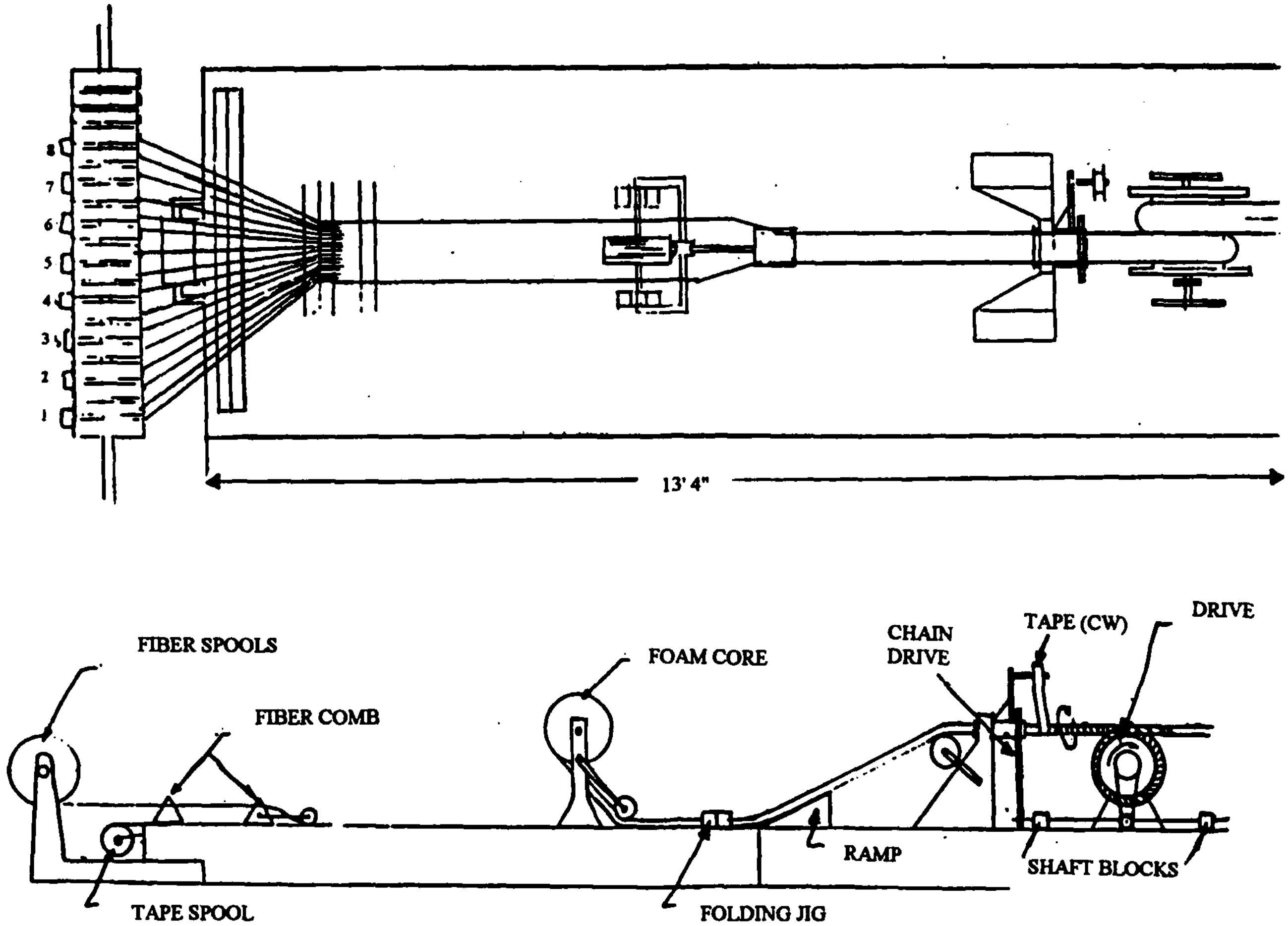
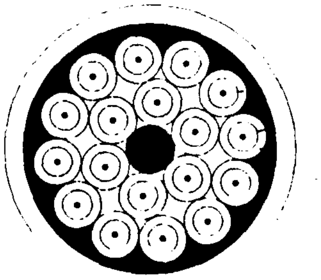



Figure A-3. FIBLOC system.

# APPENDIX B

# MANUFACTURERS SPECIFICATIONS

# SPECIFICATION GUIDE
# D-SERIES DISTRIBUTION CABLES



- OPTICAL FIBER
- ACRYLATE FIBER COATING
- COLOR CODED 900 UM DIAMETER ELASTOMERIC BUFFERED OPTICAL FIBER
- ARAMID STRENGTH MEMBER (KEVLAR®)
- CORE-LOCKED™ PVC JACKET

***(DRAWINGS NOT TO SCALE)***

| FIBER COUNT | PART NUMBER | Diameter (mm) | Weight (kg/km) | Tensile Load Rating Short Term (N) | Long Term (N) |
|---|---|---|---|---|---|
| 2 | D02-045D-■■■■/900 | 4.5 | 21 | 1,200 | 400 |
| 4 | D04-050D-■■■■/900 | 5.0 | 27 | 1,200 | 400 |
| 6 | D06-055D-■■■■/900 | 5.5 | 33 | 1,400 | 450 |
| 8 | D08-060D-■■■■/900 | 6.0 | 37 | 1,600 | 525 |
| 10 | D10-065D-■■■■/900 | 6.5 | 42 | 1,800 | 600 |
| 12 | D12-065D-■■■■/900 | 6.5 | 44 | 1,800 | 600 |
| 14 | D14-070D-■■■■/900 | 7.0 | 48 | 1,800 | 600 |
| 16 | D16-070D-■■■■/900 | 7.0 | 48 | 2,100 | 700 |
| 18 | D18-070D-■■■■/900 | 7.0 | 48 | 2,100 | 700 |
| 24 | D24-080D-■■■■/900 | 8.0 | 60 | 3,000 | 1,000 |
| 30 | D30-090D-■■■■/900 | 9.0 | 76 | 3,000 | 1,000 |
| 36 | D36-090D-■■■■/900 | 9.0 | 76 | 3,000 | 1,000 |
| 48 | D48-105D-■■■■/900 | 10.5 | 115 | 4,200 | 1,400 |
| 60 | D60-110D-■■■■/900 | 11.0 | 127 | 4,800 | 1,600 |
| 72 | D72-120D-■■■■/900 | 12.0 | 153 | 5,400 | 1,800 |
| 84 | D84-130D-■■■■/900 | 13.0 | 165 | 6,000 | 2,000 |
| 96 | D96-140D-■■■■/900 | 14.0 | 174 | 6,000 | 2,000 |
| 108 | D108-140D-■■■■/900 | 14.0 | 186 | 6,000 | 2,000 |
| 120 | D120-150D-■■■■/900 | 15.0 | 194 | 6,000 | 2,000 |
| 132 | D132-155D-■■■■/900 | 15.5 | 207 | 6,000 | 2,000 |
| 144 | D144-160D-■■■■/900 | 16.0 | 221 | 6,000 | 2,000 |
| 156 | D156-180D-■■■■/900 | 18.0 | 286 | 6,600 | 2,200 |
| Other fiber counts are available upon request. | | | | | |

*Installation loads in excess of 2,700 N (600 lbs ) are not recommended    Part Number example: D02-045D-W3SB/1UC/900

SEE FIBER SPECIFICATION AND CABLE ORDERING GUIDE FOR FURTHER DETAILS

## SPECIFICATIONS COMMON TO ALL D-SERIES DISTRIBUTION CABLES

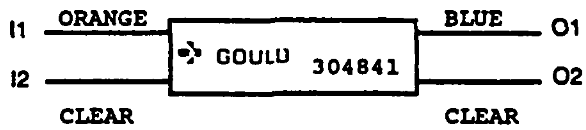
| | |
|---|---|
| Minimum Bend Radius | |
| Under Installation Tensile Load: | 20 x Outside Diameter |
| Under Long Term Tensile Load: | 10 x Outside Diameter |
| Operating Temperature: | -40°C to +85°C |
| Storage Temperature: | -55°C to +85°C |
| Crush Resistance: | 1800 N/cm |
| Impact Resistance: | 1500 Impacts |
| Flex Resistance: | 2000 Cycles |

*These specifications are subject to change without prior notification.*

Meets or exceeds BellCore requirements for intrabuilding fiber optic cables as outlined in TR-TSY-000409 and TR-TSY-000020.

INSPECTED BY 4228

## TEST RESULTS




MM-C1A-50/50-02X02

Multimode 2X2, Series A

| | |
|---|---|
| Fiber Type ......................... | MM Corning 50/125 |
| Test Date .......................... | 10-04-91 |
| Test Wavelength..................... | 850 nm |
| ORANGE(I1) IN --> BLUE(O1) OUT..... | 4.21 dB |
| ORANGE(I1) IN --> CLEAR(O2) OUT.... | 5.08 dB |
| CLEAR(I2) IN --> CLEAR(O2) OUT..... | 4.93 dB |
| CLEAR(I2) IN --> BLUE(O1) OUT...... | 4.90 dB |
| BLUE(O1) IN --> ORANGE(I1) OUT..... | 4.34 dB |
| BLUE(O1) IN --> CLEAR(I2) OUT...... | 5.17 dB |
| CLEAR(O2) IN --> CLEAR(I2) OUT..... | 4.12 dB |
| CLEAR(O2) IN --> ORANGE(I1) OUT.... | 4.87 dB |

Questions? In the U.S. 1-800-54-GOULD

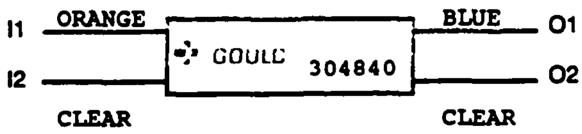

For information or questions:

Gould Inc.
Fiber Optics Division
6740 Baymeadow Drive
Glen Burnie, MD 21060 USA
Telephone (301) 787-2802
Fax (301) 787-2831


GOULD Electronics

INSPECTED
BY
4226

## TEST RESULTS




MM-C1A-50/50-02X02

Multimode 2X2, Series A

| | |
|---|---|
| Fiber Type ........................ | MM Corning 50/125 |
| Test Date ......................... | 10-04-91 |
| Test Wavelength.................... | 850 nm |
| ORANGE(I1) IN --> BLUE(O1) OUT..... | 3.99 dB |
| ORANGE(I1) IN --> CLEAR(O2) OUT.... | 4.94 dB |
| CLEAR(I2) IN --> CLEAR(O2) OUT..... | 3.28 dB |
| CLEAR(I2) IN --> BLUE(O1) OUT...... | 4.21 dB |
| BLUE(O1) IN --> ORANGE(I1) OUT..... | 3.59 dB |
| BLUE(O1) IN --> CLEAR(I2) OUT...... | 4.54 dB |
| CLEAR(O2) IN --> CLEAR(I2) OUT..... | 4.01 dB |
| CLEAR(O2) IN --> ORANGE(I1) OUT.... | 4.98 dB |

Questions? In the U.S. 1-800-54-GOULD

For information or questions:

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Fiber Optics Division
6740 Baymeadow Drive
Glen Burnie, MD 21060 USA
Telephone (301) 787-2802
Fax (301) 787-2831

GOULD
Electronics

## Gould Multimode Coupler Specifications:

| Standard Performance Characteristics | Series H | Series A |
|---|---|---|
| Operating Wavelength | 400nm to 1600nm | 400nm to 1600nm |
| Excess Loss | <0.25dB | <0.75dB |
| Coupling Ratio Tolerance | ±5.0% | ±10.0% |
| Thermal Stability | <1.0% P-P | <2.0% P-P |
| Directivity (Near End Isolation)[1] | <-40.0dB | <-40.0dB |
| Port Configuration | 1X2, 2X2 | 1X2, 2X2 |
| Lead Length | 1.0 meter | 1.0 meter |

Note 1: With output leads terminated for no reflection.

Gould specifications are guaranteed maximum values.

**ENVIRONMENTAL:**

Gould's bare fiber package has been designed to surpass the following tests:

Damp Heat: Over 1500 hours at 65°C and 85% RH
Temperature Cycling: Over 250 cycles from -40°C to +85°C
Vibration: 10g's from 10 to 2000Hz
Shock: Up to 2500 g's

**COUPLING RATIOS:** Coupling ratios of 10% to 50%.

**FIBER TYPES:** Gould's standard multimode fibers are:

Corning DWF™: 50/125 micron, NA=0.20
Corning LNF™: 62.5/125 micron, NA=0.275
Corning SDF™: *100/140 micron, NA=0.29*

Other fiber types and sizes may be ordered such as 85/125 or HCS 110/125 and 200/230.

**PACKAGES:**

Several packaging and connectorization options are available. Please see *Gould's Coupler Packaging and Ordering Information* brochure for details.

**PRODUCT CODE:**

1 3 0 0 - C X X - X X / X X - X X X X X

FIBER SIZE:
- 50/125 = 1
- 62.5/125 = 2
- 100/140 = 3

SERIES = H or A

COUPLING RATIO:
10/90, 50/50,
OTHERS

PORT CONFIGURATION:
- 1x2 = 01x02
- 2x2 = 02x02

Gould reserves the right to modify or improve these specifications without notice.

For information or questions:
**Gould Inc., Fiber Optics Operation**
6730 Baymeadow Drive, Suite D
Glen Burnie, MD 21061, USA
Telephone (301)787-3461, Fax (301)787-2831
Telex 898029, Toll Free 1-800-54-GOULD

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# APPENDIX C

# PERIMETER INTRUSION DETECTION SYSTEM COMPARISON FACTORS

# PERIMETER INTRUSION DETECTION SYSTEM COMPARISON FACTORS

## C.1 INTRODUCTION.

High-value and sensitive assets are often safeguarded from damage or loss by a variety of intrusion detection sensors and other protective devices. Depending upon the installation or facility where the asset is located, access to the material may be protected by a one or more layers of defensive devices or systems. These include physical barriers, such as fences, deterrent devices such as armed guards and barbed wire, and intrusion detection sensors, which provide warning of prohibited entry attempts. The Fiber Optic Perimeter Intrusion Detection and Location (FIBLOC) system being developed by ANRO Engineering is an example of a perimeter intrusion detection sensor. An overview of the FIBLOC system is given below.

Multiple, complementary sensors and protective devices are used to provide an increased overall level of protection because each individual type of design has inherent limitations or weaknesses. For example, certain sensors can be degraded by heavy precipitation, whereas other types are not affected by rain, snow, etc. The overall probability of detection of illicit access to protected assets is increased by using collateral mixes of types of sensors and devices deployed in layers.

Intrusion detection sensors include motion detectors, pressure sensors, infrared and visual monitors, and seismic, magnetic, ultrasonic, radar, and electric-field sensors as examples. Intrusion detection sensors can be deployed in the immediate vicinity of the protected asset, and in layered, or overlapping defenses outward to perimeter locations. Perimeter intrusion detection systems are utilized to provide increased warning time of entry attempts, and take advantage of different technologies available to increase the probability of detection while minimizing the occurrences of false alarms and nuisance alarms.

This paper provides a brief comparative analysis of currently available perimeter intrusion detection systems with applications similar to FIBLOC. Sensor systems normally deployed in interior locations, such as ultrasonic and infrared motion detector sensors, are not addressed here. Exterior lighting and camera systems, which are typically used to locate and identify potential intrusion events, are likewise not addressed here. A cost comparison will be provided for those sensors similar to FIBLOC.

## C.2 BACKGROUND.

Figure C-1 provides a hypothetical illustration of a layered perimeter intrusion detection defense. No one particular protected installation may use all of these types of sensor systems, and the order and position of the sensors will vary between locations, based upon the criticality of the protected asset, local environment, cost, perceived threat, and other factors. A brief description of each of the sensor types is given below, highlighting some of the applications for the sensor systems, and their inherent advantages and limitations. A review of these factors indicates the benefit of using multiple types of sensors to achieve a higher overall probability of detection, with a lower false alarm and nuisance alarm occurrence rate.

It will be shown that each type of sensor has capabilities intended to counter a particular type of intrusion threat, and that none of the sensors can guarantee a 100% probability of detection, with a zero false/nuisance alarm rate. A greater degree of protection is provided when different types of sensors are deployed in layers, or in conjunction with each other.

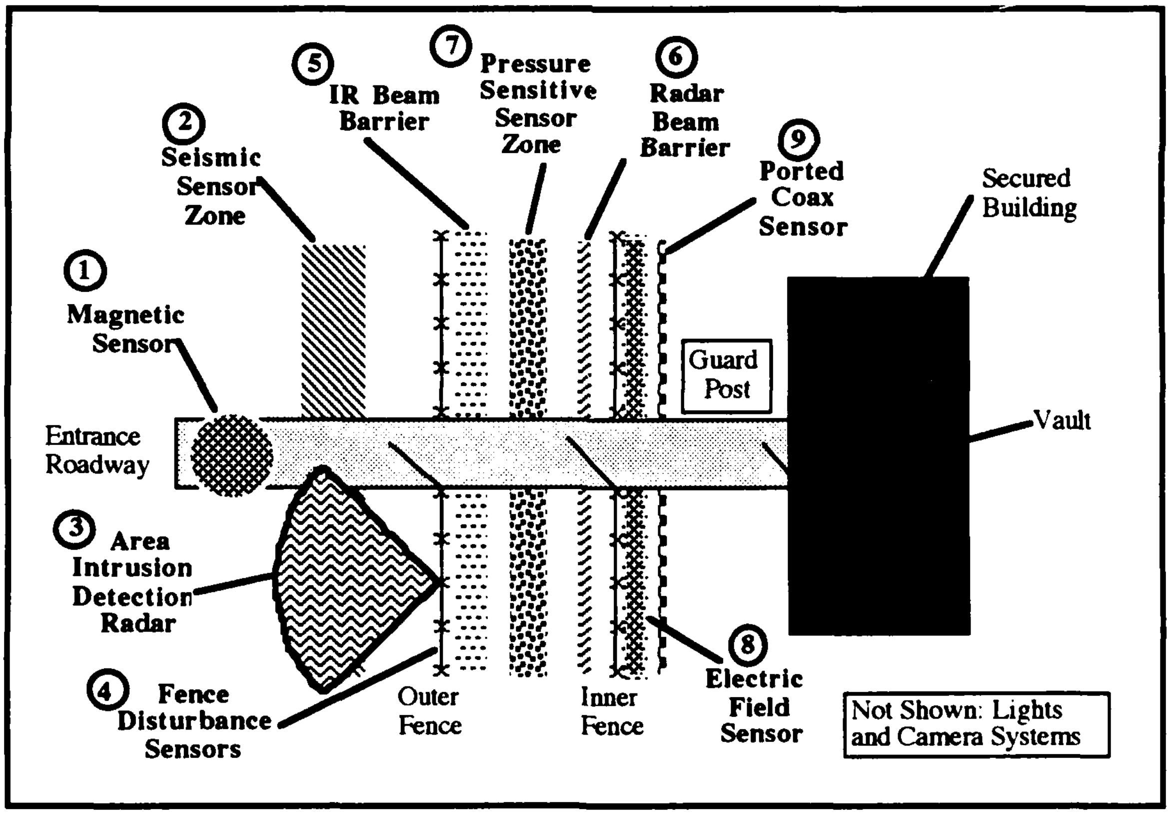


Figure C-1. Perimeter intrusion detection systems.

## C.3 SENSOR SYSTEM DESCRIPTIONS.

Brief overview descriptions for each of the sensor system types depicted in Figure C-1 are given below.

### C.3.1 Magnetic Sensors.

Magnetic intrusion detection sensors detect the change in flux density caused by the proximity of ferrous materials, such as found in vehicles. Magnetic sensors are typically designed to detect and, potentially, identify by type vehicles entering a protected zone. Military applications, such as REMBASS, employ magnetic sensors to detect trucks, tanks, and other vehicles within the area where the sensors are deployed, such as a roadway. A coarse estimate of the type of target can be derived by the magnitude of the magnetic deflection at the sensor, and speed and direction may be disclosed by a using a series of sensors and appropriate processing techniques. The magnetic sensors used in the REMBASS system provide detection of personnel carrying weapons to a range of about 3 meters, wheeled vehicles to within 15 meters, and tracked vehicles within 15 meters.[1]

Magnetic sensors can be buried in a roadway, and provide undetected monitoring. The area of coverage of a single sensor, however, is limited, and area coverage requires a number of sensors deployed in an array or a line. Single sensors deployed in a limited area, such as a roadway, can be avoided if their presence is known or suspected. These sensors are useful in locations where notification of the approach of a vehicle is desired, such as a gate or a traffic light. Magnetic sensors have been developed for deployment in a line configuration, such as the MAID/MILES systems, which are used in perimeter intrusion detection.

### C.3.2 Seismic Sensors.

Seismic sensors detect vibrations caused by footsteps or passing vehicles. Coverage of an area or a zone requires an array or line of sensors. Signal processing can distinguish the type of disturbance, to some degree. Examples of systems employing seismic sensors include MIDS and TIDS. The detection range of the seismic sensors used in REMBASS offer detection of personnel within 50 meters and tracked and wheeled vehicles within 350 meters.

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[1] Base and Installation Security System (BISS) DT&E Technical Report AD-TR-88-81, 3246th Test Wing, AFSC, Eglin AFB, FL, August 1988.

False alarms or nuisance alarms can be induced in buried seismic sensors by motion of the earth caused by the movement of trees in the wind, thunder, and large animals. Some soil conditions (e.g., sandy or marsh) diminish the effectiveness of seismic sensors. Similar to magnetic sensors, seismic sensors may be avoided by penetrators if the location is known.

### C.3.3 Radar Area Coverage Sensors.

Radar intrusion detection sensors are identified in two general classes, based on the coverage techniques. One class of radar sensors employ a narrow beam to create an invisible barrier that detects intrusion attempts crossing the protected zone. The barrier class of radar intrusion detection sensors includes the RACON sensors, and will be addressed further below. The second general class of radar sensors used to provide intrusion detection provide an area coverage, either by scanning a beam over an area, or by employing a broad beam pattern. Examples of area coverage sensors include the FOLPEN radar, the MIRSS radar sensor and the Ultra-Wideband (UWB) IDAS sensor. The FOLPEN radar program was terminated in 1989, and production of the MIRSS is limited to 40 units in 1990.[2]

Area coverage radar intrusion detection sensors are most effective over flat, open ground, and are capable of detecting running, walking, and crawling intruders. The FOLPEN radar is specifically designed to penetrate foliage to detect intruders at ranges up to 300 meters, and up to 700 meters over open terrain. The IDAS sensor provides coverage over an arc of 140 degrees, and up to 250 feet in range.[3]

Recent advances in IDAS signal processing permits discrimination between humans and other moving targets, such as branches blowing in the wind. The IDAS UWB sensor has the advantage of being nearly undetectable by conventional receivers.

2 Intrusion Detection System for Tactical Air Control System Units, $C^3$ Division Report, ANSER, March, 1990.

3 IDAS Product Brochure, Sperry Marine Inc., Charlottesville, VA, 1989.

### C.3.4 Fence Disturbance Sensors.

Where sensitive assets are protected by fences, sensors are frequently used to detect attempts to gain access by going over, under, or through the fence. One general class of fence disturbance sensors are commonly called "fence shakers", and simply detect abrupt movements of the fence caused by an intruder. Signal processing techniques are employed to distinguish movement caused by the wind and possible unauthorized access attempts. Fence disturbance sensors include electromechanical and mercury switches, and various types of cables which detect motion, distortion or being severed.

Fence disturbance sensors are ineffective when the fence is avoided, such as by vertical entry into the protected area. In addition, fence disturbance sensors are susceptible to nuisance alarms by passing trucks, wind gusts, and other benign causes.

### C.3.5 Infrared Beam Barrier Sensors.

Infrared (IR) sensors can be used to detect the presence or motion of intruders by their temperature variations against the perceived background. These passive sensors are typically used in interior installations, or where there is not a large variation in ambient temperature. An example of an outdoor application of a passive IR sensor is used in the REMBASS system, where a simple 2-beam installation senses the change in background temperature due to the presence an object, and can determine direction of travel (left-to-right, or right-to-left).

For perimeter intrusion detection applications, active IR barriers are established by a beam of IR energy transmitted from a source to a receiver at a line-of-sight terminal. An alarm is sounded when the IR beam is interrupted, or "broken", by an intruder. The IR beam is narrow, and must be mounted near the surface to prohibit an intruder from passing under the beam. Several beams can be stacked in a vertical "fence" array to keep an intruder from passing over the beam. Adjoining arrays can be overlapped to provide a continuous barrier, as shown in Figure C-2. The IR beam is not normally visible to the naked eye, which can provide a measure of surprise to an intruder.

An example of an IR barrier type intrusion detection system is manufactured by Bird-Eye Security International, Inc., Hackensack, NJ as their Model VI. The maximum estimate range of a set of the Model VI IR beam sensors is about 150 meters.[4]

Careful placement of the transmitter and receiver is required to prevent obstruction of the transmitted beam. Depressions in the ground level between the sensors can provide "shadow" areas, and permit undetected intrusion.[5]

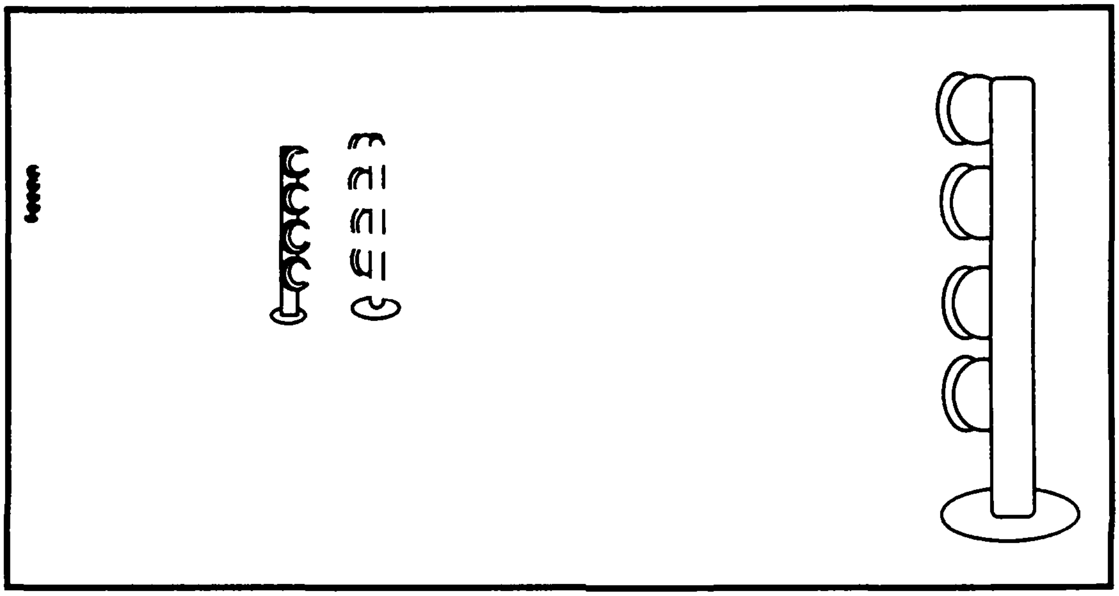

Figure C-2. IR beam barrier sensors.

To be effective, the terrain should be flat and unobstructed. IR barriers are disrupted by heavy snow, rain, and fog. Deep snow coverage can provide cover for a crawling intruder. In addition, IR sensor alignment is very sensitive, and movement of the mounting fixture (for example, by freezing of the ground) can disrupt coverage.

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4 Model VI IR Sensor Qualification, Test and Evaluation Report, 3246 Test Wing, AFSC, Eglin AFB, FL, June 1989.

5 Capability for Intrusion Detection at Nuclear Fuel sites, Army Mobility Equipment R&D Command, March, 1978.

### C.3.6 Radar Beam Barrier Sensors.

As opposed to the area coverage radar sensors discussed in item 3 above, radar beam barrier sensors are usually used to establish a detection zone around a sensitive asset. Two general types of radar barrier sensors are employed; the first operates in a bistatic mode, where the transmitter and receiver create a beam that is interrupted by an intruder, and the other type operates in a monostatic mode as a motion detector sensor. That is, motion is detected by a Doppler shift in frequency. RACON Models 14xxx, 16xxx, and RDS-1000 are commercially available examples of radar bistatic sensors. RACON Models M-2xx and M-5xx are monostatic motion detector sensors.[6]

Radar barrier sensors suffer some of the same restrictions as the IR barrier sensors. For example, careful placement of the transmitter and receiver is required to prevent obstruction of the transmitted beam. Depressions in the surface may provide "shadow" areas reducing effective coverage, and shadowing effects from building, trees, etc., can cause zones of insensitivity.

The radar beam is quite broad for much of the coverage area, so stacking is not required. However, the radar beam is essentially a point source at the transmitting antenna, creating a gap around the mounting fixture. A "basketweave" or staggered placement of transmitter/receiver pairs, as illustrated in Figure C-3, is used to provide overlapping coverage to assure continuous coverage. In some instances, both IR and radar beam barrier sensors are used in a complementary installation.

As opposed to the IR sensors, radar sensors are not generally affected by precipitation, although deep snow cover can hide a crawling intruder. RF sensor alignment is not as critical as IR sensors. Determination of the location of an intrusion alert is limited to the span of the sensor. The RACON radar sensors described above provide coverage up to 1500 feet per span.

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[6] RACON Incorporated Brochure, Seattle, WA, September, 1991.

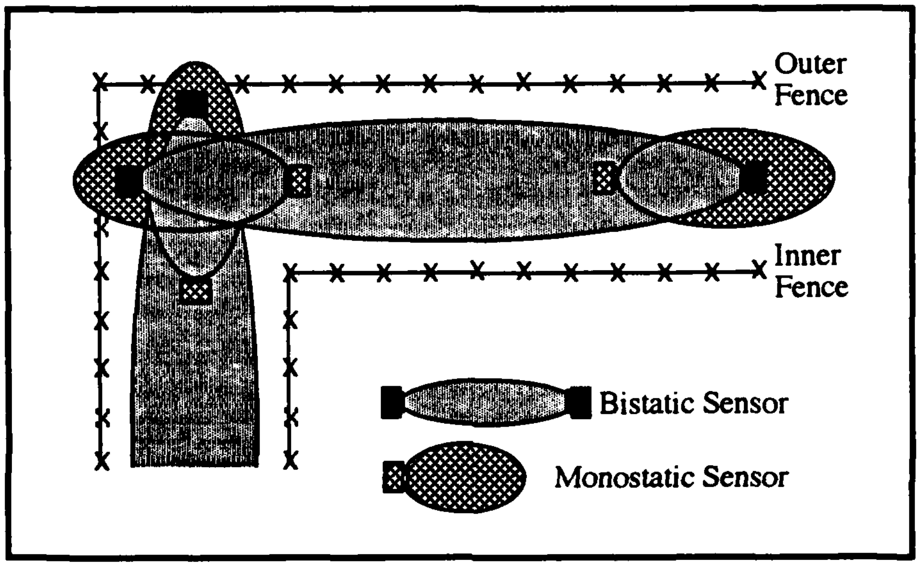


Figure C-3. Radar beam barrier sensors.

### C.3.7 Pressure Sensitive Sensors.

An example of a simple pressure sensitive sensor is the familiar air-filled rubber hose stretched across a roadway to count passing vehicles. Another example is a floor mat which includes electrical contacts which are closed when pressure is applied. For protection against wear and the elements, and for covertness, pressure sensitive sensors are usually buried in soil or gravel.

A more recent innovation is the use of fiber optic cable as a pressure sensitive sensor. A physical distortion of the cable affects the phase of a transmitted light signal, which when detected, indicates pressure applied to the cable. In a buried installation, pressure applied to the surrounding surface is transmitted to the cable. The area of coverage is limited to a relatively narrow zone along the length of the cable. The expand the width of an area, the cable is usually laid in a serpentine fashion. The increase in the area of coverage is at the expense of the required additional cable.

One commercially available fiber optic pressure sensor is offered by Fiber SenSys, Beaverton, OR.[7] Figure C-4 illustrates a typical buried deployment. In this installation, a 600 meter cable provides an area of coverage 100 meters by 6 meters. The Fiber SenSys system offers no indication of the location of an intrusion within the area of coverage.

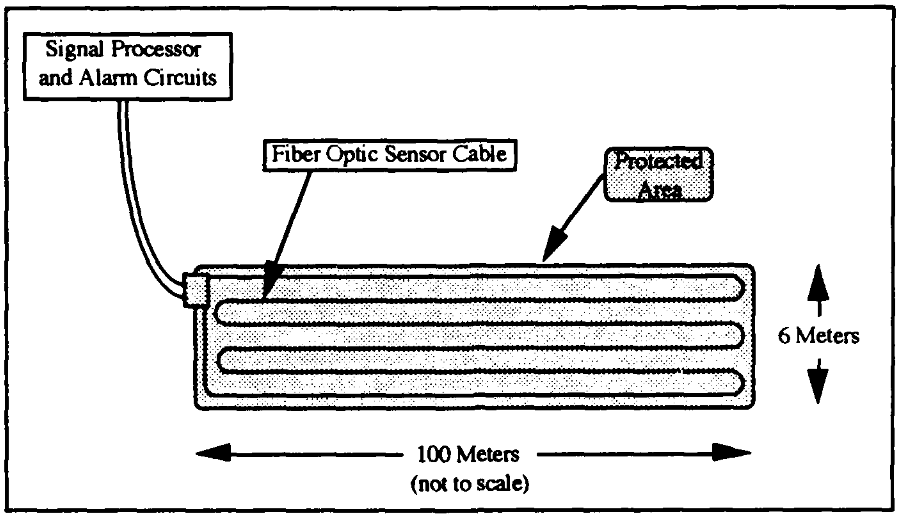


Figure C-4. Fiber SenSys fiber optic intrusion detection system suggested deployment.

The FIBLOC system, however, does provide location information within each zone of coverage, which speeds response time and focuses protective measures. FIBLOC sensing cables can be up to 1 km in length, and be deployed around buildings, fences, and other obstructions. In addition, the area where the FIBLOC cable is deployed can be rolling or uneven, and does not have to be flat and clear, as with the IR and radar beam barrier type systems.

Figure C-5 shows schematically how the sensing capability of the FIBLOC cable is "segmented" to give an accurate indication of the location of an intrusion. Note that the cable itself is not segmented, but that discretionary sense zones within the cable length are sensitized to identify where along the cable intrusions occur. The discretization segments are on the order of 10 to 30 meters. When broad areas are covered, two or more cables can be laid in parallel, and the sensing segments staggered to provide a vernier effect on intrusion locations and route.

[7] Fiber SenSys, Inc. Brochure, Beaverton, OR, February, 1991.

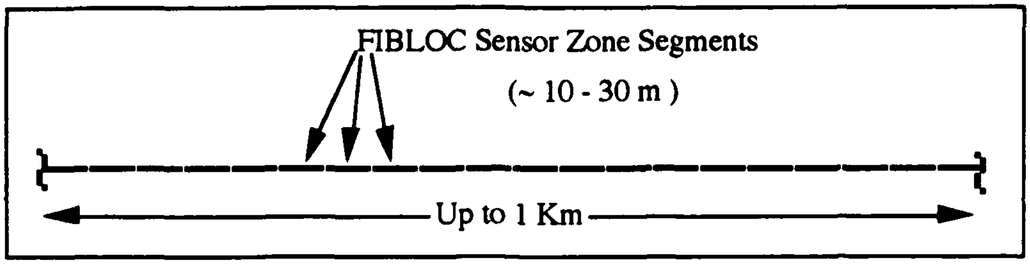


Figure C-5. FIBLOC sensor cable configuration.

In Figure C-6, a depiction of a potential deployment of a FIBLOC system is shown. In this illustration, three FIBLOC cables with 15 meter sensing segments are laid between the inner and outer fences, which are separated by 20 meters. Note that the area of an intrusion is pinpointed to within a much smaller zone (highlighted in the figure). Simple processing and display techniques can indicate the point of entry and follow the path of an intruder in the area between the fences. It may also be possible to determine the size of the intruding force by the number of adjacent sensing segments that simultaneously indicate alarms.

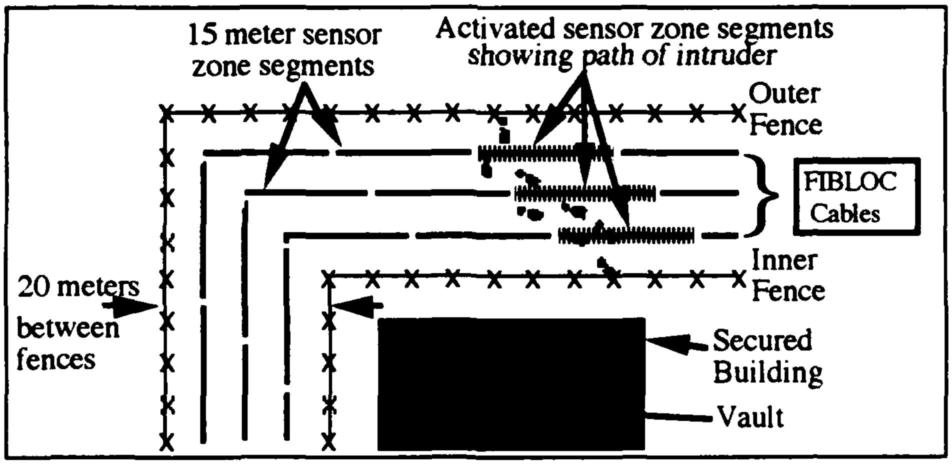


Figure C-6. Intruder location and tracking using FIBLOC system.

### C.3.8 Electric Field Sensor.

An electric field is established when one wire, which carries a low level voltage signal, is paralleled by the earth, or one or more other wires which act as receivers. The electric field between these wires is changed when a conducting mass, such as a human body, enters the field. Detection of a change in the electric field can indicate the presence of an intruder. An example of the electric field sensor is the REPELS system.

Electric field sensors, to be effective, must be rigidly mounted to prevent relative movement among the elements. Therefore, deployment of these sensors is typically restricted to closed spaces, or mounted on rigid fences or walls. Location information is limited to the length of the field.

### C.3.9 Ported Coax Sensor.

The ported coax sensor operates in a manner similar to the electric field sensor. That is, a field is established along the coaxial cable by holes, or ports, cut out of the surrounding shield portion of the cable. Ported coax sensors are frequently buried for protection and covertness, and are also used in interior locations. An example of a fielded ported coax sensor system is the PINTS system.[8]

Ported coax sensor systems are typically used in interior locations. Intrusion detection location information from ported coax systems is also restricted to the length of cable in each deployment.

[8] Minutes of the PINTS/TIWG Meeting, Test Integration Working Group, Fort Belvoir Research, Development and Engineering Center, Ft. Belvoir, VA, 22 April, 1986.

## C.4 PERIMETER INTRUSION DETECTION SENSOR COST COMPARISONS.

### C.4.1 Fiber SenSys, Inc. Fiber Optic Intrusion Detection Systems.

A fiber optic intrusion detection system is offered by Fiber SenSys, Inc., Beaverton, OR for deployment at sensitive installations. Cost data as provided by Fiber SenSys is shown in Figure C-7 for systems with remote signal processing and alarm circuitry, for local, distributed, circuitry, and for the sensing fiber optic cable alone. As expected, the cost per meter decreases for longer cable lengths, as shown in the figure. The cost of a remotely operated system employing 600 meters of sensing cable is shown to be $4998, plus accessories. This length of sensing cable provides coverage of an area approximately 100 meters x 6 meters due to the serpentine deployment of the sensing cable. Additional units would be used to provide coverage of larger areas; ten units would be required to provide coverage of a 1 kilometer perimeter.

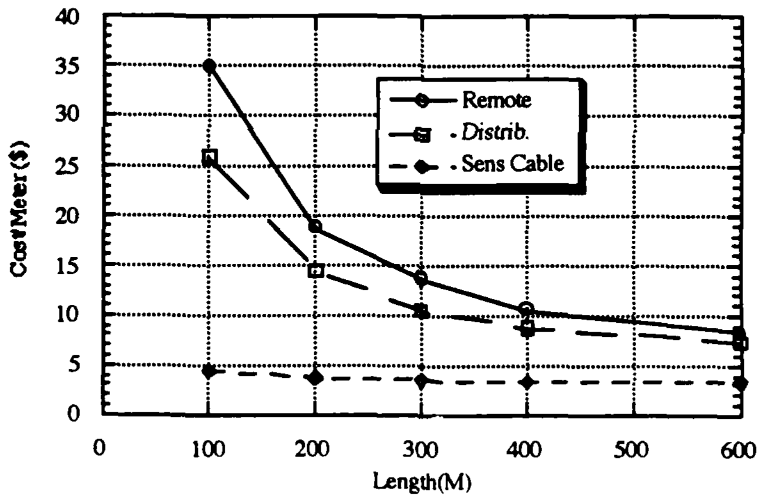


Figure C-7. Fiber SenSys cost data.

### C.4.2 RACON Incorporated Radar Beam Barrier Intrusion Detection Systems.

Examples of radar beam barrier type intrusion detection systems are offered by RACON Incorporated, Seattle, WA. RACON provides both bistatic (beam interruption) and monostatic (motion detection) radar sensors. The RACON model series 14100, 1600, and RDS-1000 are bistatic operation devices, and the model series M-201 and M-501 are microwave motion sensors. The basic advertised dealer cost for these units is shown in Figure C-8 below. There are numerous accessories available for all of the equipment, including battery and solar power options, and radio links for remote operation. Some additional equipment is required to implement an operational system.

Assuming a rectangular installation where four radar beam intrusion detection sections would be necessary, the estimated hardware cost for such a system would be 4 x $1,595, or a total of $6,380.

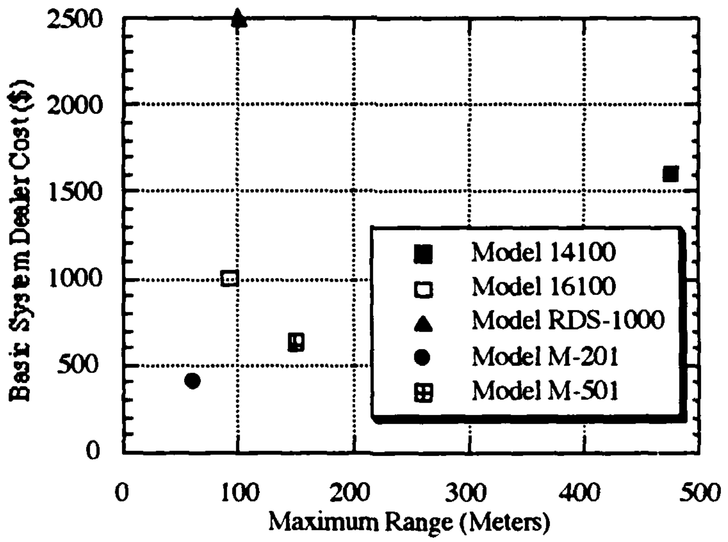


Figure C-8. RACON radar beam intrusion detection system costs.

### C.4.3 Infrared Beam Barrier Intrusion Detection System.

As discussed in section 5 above under the sensor system descriptions, IR beam barrier intrusion detection systems operate in a bistatic mode. That is, an IR beam is projected from the transmitter location towards a receiver at some distance. Each section of an IR barrier then consists of a transmitter and a receiver.

Depending upon the installation, a section of an IR barrier can provide intrusion detection coverage for ranges to 120 meters. Each IR section costs approximately $7500. A 1 kilometer perimeter defense system would then total approximately $67,500.

### C.4.4 Summary of Perimeter Intrusion Detection System Costs.

Based on the information above, the following table summarizes the comparative costs for a 1 kilometer perimeter intrusion detection system. These cost estimates consider only the hardware/embedded software for the sensors, and does not include system installation, integration, operator consoles, alarm displays, and ancillary equipment.

| Equipment Type | Manufacturer | Cost/1 km |
|---|---|---|
| IR Beam Barrier | Bird-Eye Model VI | $67,500 |
| Radar Beam Barrier | RACON Model 14100 | $6,380 |
| Fiber Optic - non locating | Fiber SenSys | $49,980 |
| FIBLOC | Developmental - ANRO | $22,600 |

# APPENDIX D

U.S. PATENT 4,931,771, June 5, 1991
OPTICAL FIBER INTRUSION LOCATION SENSOR FOR PERIMETER PROTECTION OF PRECINCTS

TRADE MARK ALLOWANCE, Serial Number 74/114421
PERIMETER PROTECTION FIBLOC, ANRO Engineering

# United States Patent [19]

**Kahn**

[11] **Patent Number:** 4,931,771

[45] **Date of Patent:** Jun. 5, 1990


[54] **OPTICAL FIBER INTRUSION LOCATION SENSOR FOR PERIMETER PROTECTION OF PRECINCTS**


[75] Inventor: Walter K. Kahn, Bethesda, Md.

[73] Assignee: Aaro Engineering, Inc., Lexington, Mass.



[21] Appl. No.: 249,823

[22] Filed: Sep. 27, 1988

[51] Int. Cl.$^5$ .............................................. G08B 13/18

[52] U.S. Cl. ............................ 340/556; 250/227.14; 340/525

[58] Field of Search .............. 340/556, 555, 557, 550, 340/524, 525, 541, 666; 250/227, 231 R; 73/705


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4,482,890 11/1984 Forbes et al. .................. 340/556
4,591,709 5/1986 Koechner et al. ................ 250/221

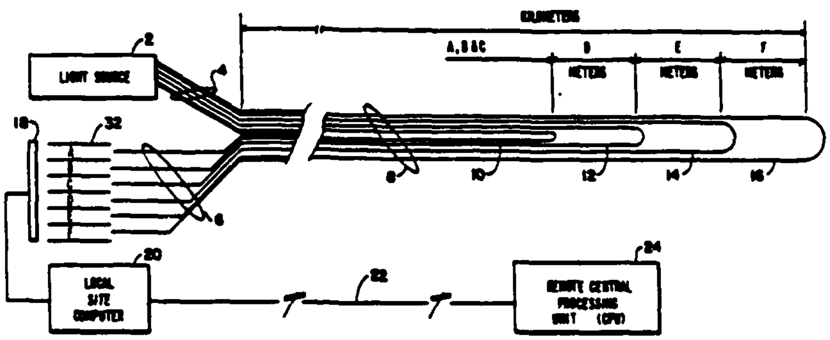


*Primary Examiner*—Reinhard J. Eisenzopf
*Assistant Examiner*—Robert W. Mueller
*Attorney, Agent, or Firm*—George Grayson

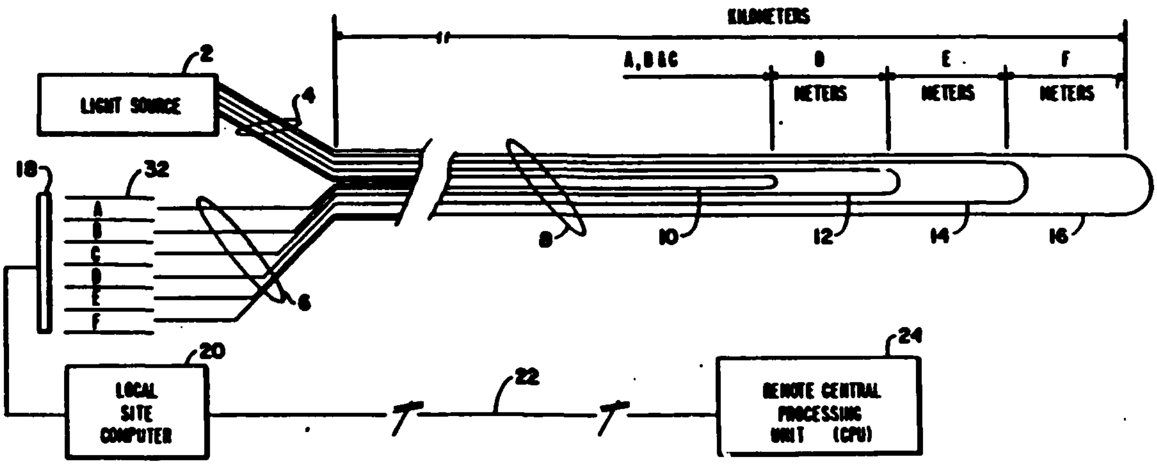

[57] **ABSTRACT**


A Precinct Protection System includes a laser source of light which is applied at the input to a bundle of light transmissive fibers. The fibers are gathered in a cable in loops of varying lengths so that the fibers enter and exit the cable at one and the same end. The cable is placed along a line adjoining or surrounding the precincts to be protected. An intruder traversing the line or protected perimeter will disturb one or more of the fiber optic loops of the cable. The circumstance and locality of the disturbance produced by the intruder are indicated on an analog or digital display.

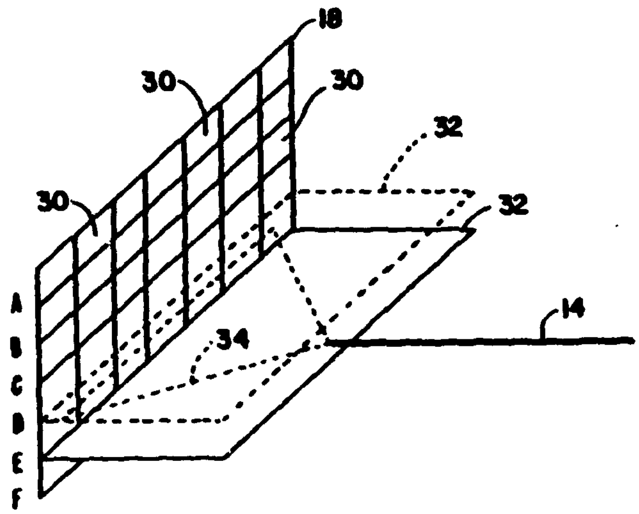

**13 Claims, 4 Drawing Sheets**




PERIMETER PROTECTION SYSTEM 1




PERIMETER PROTECTION SYSTEM I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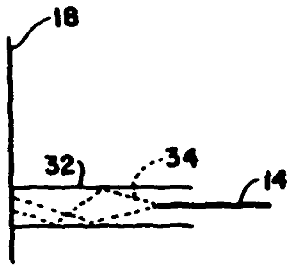
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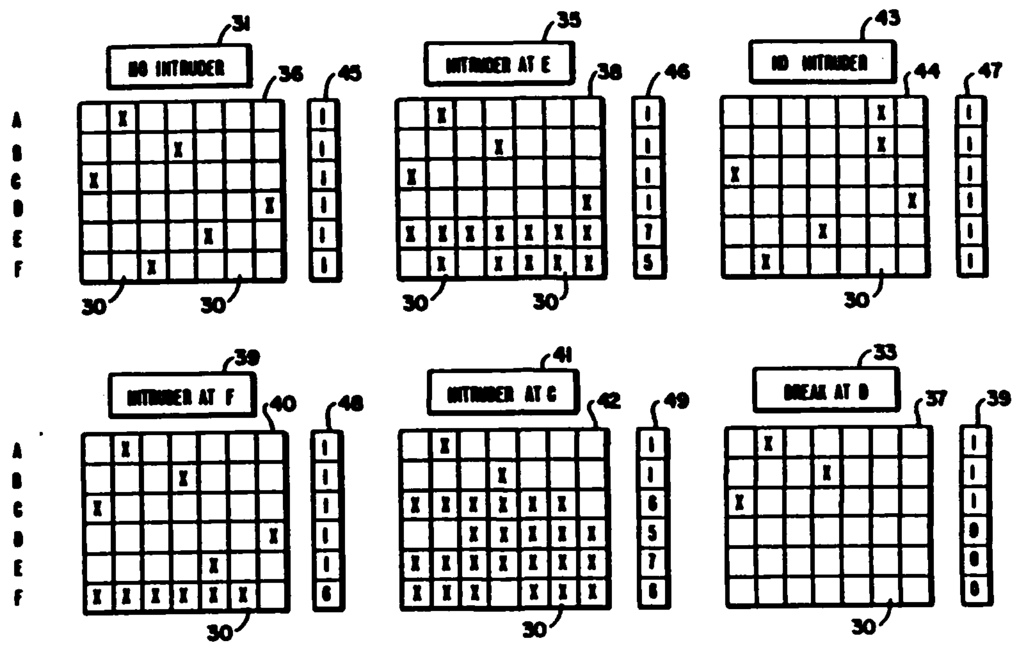
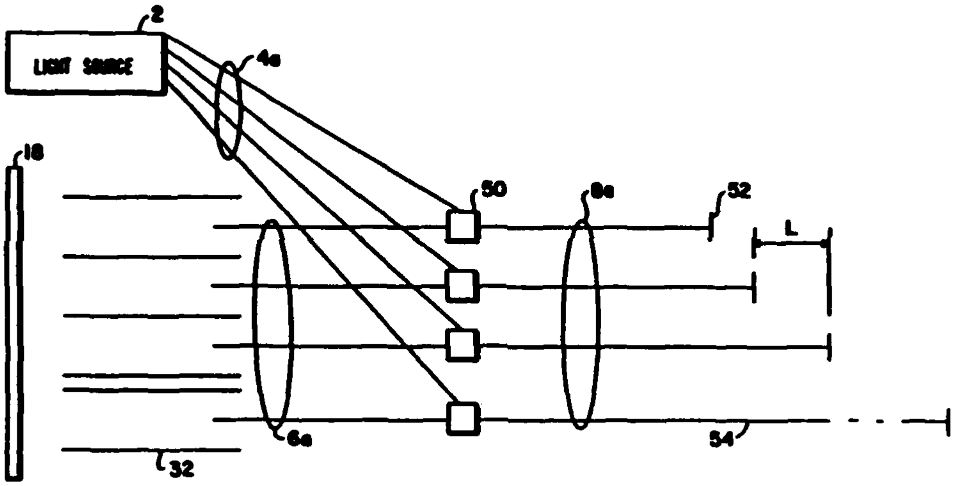



PHOTO-RECEPTOR
ALPHANUMERIC AND DIGITAL DISPLAYS



2
LIGHT SOURCE
4a
18
50
8a
52
L
6a
54
32

# OPTICAL FIBER INTRUSION LOCATION SENSOR FOR PERIMETER PROTECTION OF PRECINCTS

## BACKGROUND OF THE INVENTION

1. Scope of the Invention

This invention relates to the perimeter security and surveillance field, and more particularly to the use of fiber optic bundles for protecting the perimeter of an extended area precinct by detecting traverse of the perimeter by an intruder and localizing the point at which the perimeter was traversed.

2. Description of the Prior Art

There is a need to provide an economic means to protect literally miles of a preferred perimeter against unauthorized intruders under all conditions. A number of perimeter protection schemes have aimed to accomplish this. These schemes include the use X-band line-of-sight radar beams, free space infrared surveillance equipment, and buried leaky wave coaxial cables.

These systems have known limitations. For example, radar and free-space infrared systems are limited in their reliability and range by beam spreading, sidelobes, and variable attenuation due to weather conditions. Leaky wave systems are severely range limited (hundreds of feet) and are costly to install and maintain.

These limitations are overcome by fiber optic sensors which can be deployed over several miles and are also immune from electromagnetic interference (EMI) electromagnetic pulses (EMP).

Fiber optic sensor technology is described in an Optical Engineering/March/April 1985/Vol. 24 No. 2 article by Charles M. Davis entitled "Fiber optic sensors: an overview". The optic sensors in the article depend on the creation of sufficient distortion of the fiber to give rise to a dependably detectable reflection; or a sufficient distortion of the fiber to cause a dependably detectable change in transmission amplitude (power). These schemes utilize special localized (periodically repeated) sensor components or periodically repeated special sensitizing features, such as microbend deformers. Alternatively the fiber may be terminated in a mirror and interference between the incident and reflected wave detected. Such interferometer-detector arrangements are extremely delicate and prone to false alarms.

U.S. Pat. No. 4,696,889 discloses a method and apparatus wherein the exiting light from the trunk of a fiber optic assembly is projected onto a single photosensitive surface.

## OBJECT OF THE INVENTION

It is an object of the invention to have an improved perimeter protection system.

It is another object of the invention to have a more cost effective perimeter protection system.

It is yet another object of the invention to have a system with a greater probability of intrusion detection.

It is still another object of the invention to have a system with the capacity to localize the point of intrusion to within a particular several meters of the protection line.

It is yet another object of the invention to render the detection system insensitive to details of terrain, electromagnetic interference and initial placement of the cable.



## SUMMARY OF THE INVENTION

The above objects and advantages are achieved in a preferred embodiment of the present invention. According to the preferred embodiment, the Perimeter Protection System includes a cable made up of a multiplicity of multimode gradient index fiber loops which receive light energy from a laser source. The propagation of light waves through each fiber generally takes the form of a meandering beam.

The lengths of the fiber loops differ by predetermined amounts according to the precision within which the location of an intruder needs to be delimited within the complete perimeter to be protected. The arrangement loop within the cable is such that an intruder will disturb one loop over the length furthest from the light source, two loops over the next length, and all of the loops over the length nearest the light source.

The output beam from each fiber is projected onto a display. The display includes a number of areas, one for each fiber. Each area is optically isolated by a pair of mirrors or optical equivalent. For example, the boundaries of a clear slab (step index slab fiber) act as mirrors by total internal reflection.

Each area includes a number of photo-receptors. With no intruder, each fiber excites one cell in its respective area. When an intruder disturbs any part of the cable, minute distortions in the disturbed fibers are induced. In view of the large number of axial periods of the beam affected, the position and slope of the output beam is altered. These dynamic changes are captured on a display and interpreted by an operator or alternatively, they may be stored in a computer, processed and interpreted automatically.

After detecting an intruder, the system reverts to a (new) state of readiness as required to detect a subsequent intrusion in the same manner as described above. The analog display could be a persistent photosensitive screen. The time constant governing the persistence is so chosen that points not constantly illuminated by light arriving from a fiber will fade in some predetermined time, the reset time, fixed initially in the design or variable at the command of the system operator. Since the positive indication of the system derive from the observation of dynamic changes, it is not required that this new final quasi-static state of the analog display, arrived at after the dynamic changes concomitant with an intrusion which led to the characteristic display signaling this fact and the location of the intrusion, be the same as the initial state before the disturbance.

Each area may include a number of cells. Each cell will generate an electrical signal when exposed to the output beam. A digital display will display a decimal count of the number of generated signals.

Another alternative may be to provide an alphanumerical display responsive to the generated signals to spell out the intrusion location.

The novel features which are believed to be characteristic of the invention both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying drawings. It is expressly understood, however, that each of the drawings is given for the purpose of illustration and description only and is not intended as a definition of the limits of the present invention.

## DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an overall block diagram of the Perimeter Protection System.

FIG. 2a shows the projection of an output beam from a fiber optic loop onto a display.

FIG. 2b shows a side view of the output beam being reflected onto a display area by a pair of mirrors.

FIG. 3 shows the various display configurations.

FIG. 4 shows another embodiment of the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows an overall diagram of a perimeter protection system 1 using fiber optics as the means of sensing the location at which an intruder crossed the perimeter of a protected area. A light source 2 typically a commercially available coherent CW laser source provides light energy to one end of a cable 4 made up of a multiplicity of commercially available high numerical aperture (N.A.=0.2 to 0.3) multimode gradient index fiber optic loops 10, 12, 14 and 16 contained in a sensor cable 8. Note that for the simplicity of the description, only four loops are identified specifically, it is obvious that many more loops are feasible. For example, a two kilometer cable 8 could comprise twenty optical fiber loops with the capacity to detect traverse of the two kilometer line protected by the sensor cable by an intruder with the capacity to localize the point of intrusion within one of the twenty 100 meter long (incremental loop) lengths along the cable 8.

The loops 10, 12, 14, and 16 terminate in a cable 6 and the output light beams are projected directly as well as reflected by mirrors 32 onto selected row areas of a photo-receptor display 18. The mirrors 32 also optically isolate the row areas A through F of display 18 from each other.

The cable 8 is installed along the periphery of the area precincts to be protected and may be a number of kilometers long. Each successive loop protects an additional incremental length of the periphery up to typically 100 meters. Loop 16 protects incremental length F, loop 14 protects length E, loop 12 protects length D, loop 10 protects length C, and loops not shown protect lengths B and A respectively. The output beam from loop 16 is sensed by row area F of display 18. Similarly, the output beams from the other loops are sensed by their respective row areas. Therefore periphery lengths A through F are reflected in row areas A through F of display 18.

The output of display 18 may be applied to a Local Site Computer 20. A remote CPU 24 may receive information on an intrusion into the protected area over communication lines 20 to alert personnel to take a prescribed action.

Propagation within a gradient index fiber generally takes the form of a beam or beams. The beams meander through the fiber, i.e. the center of the beam follows a trajectory which oscillates about the fiber axis. The amplitude and character of a particular meander trajectory depends on the initial conditions of beam injection as well as imperfections of the fiber. The axial period of the oscillation is determined by the gradient index profile, but is generally of the order of several fiber diameters.

It is well known that mechanical distortion of the fiber, such as may be produced by a footstep on the cable 8, induces minute distortions in the fiber, which, in view of the large number of axial periods affected, completely alter the position and slope (center and phase front) of the output beam. This change is, of course, a dynamic one. As the pressure of the footstep increases from zero to its maximum value, the position and the slope of the output beam continuously varies through all possible positions of its range.

If an intruder steps on cable 8 in length E, then only loops 14 and 16 are distorted. This distortion is sensed by display 18 in row areas E and F. Row areas A, B, C, and D of display 18 show no change since the shorter loops are not distorted. In the instance of buried cables, the probability of detection of an adult intruder is increased by the use of three cables 8 placed approximately 25 centimeters apart.

A radical trauma to the sensor cable 8, such as one that results in the cable 8 being cut into two parts, anywhere along its length would be immediately apparent from a characteristic display. For example, a cut through segment D would result in the complete blanking of row areas D, E and F of display 18.

FIGS. 2a and 2b show the projection of the beam from the end of loop 14 onto a row area E on display 18. Each row area A through F contains a number of cells 30. Each cell may be typically a photo-detector or an area on the face of a cathode ray tube (CRT).

Referring to FIG. 2a, the spacial sector available to the beam 34 would be conical in shape if it were not limited by the reflecting surfaces of the two mirrors 32 which bound row area E. FIG. 2b shows a side view of a typical beam 34 from the end of fiber loop 14 being reflected by the two mirrors 32 onto the cells 30 of display 18.

FIG. 3 shows the configurations 38, 40 and 42 of the cells 30 on the surface of display 18 the instant the intruder disturbed a length of cable 8, FIG. 1. Also shown are two possible steady-state configurations 36 and 44.

Assume cable 8 was buried sufficiently below the earth's surface to avoid exposure and yet close enough to the earth's surface so that enough force resulting from the intruders footprint is transferred through the earth to perturb the fiber optic line. If the fiber optic line is not restored to its previous fiber optic line, then a new steady-state configuration 44 will result. A change therefore in the new steady-state configuration may again indicate the presence of any later intruder.

The dynamic character of the positive indication of an intruder and the ability of this system to accept any new steady-state configurations reduces considerably the probability of false alarms due to changing weather conditions or after disturbance of the system by authorized or detected innocent passage.

Configuration 36 shows that each loop 10 through 14 and the two loops not shown excite one cell 30 of their respective row areas A through F indicating that no part of any cable 8 length A through F is being disturbed.

Configuration 38 indicates that the intruder is stepping on cable 8 somewhere along length E thereby disturbing only loops 14 and 16. The loops 10 and 12 as well as the loops not shown are not disturbed. Cells 30 of row areas E and F are therefore excited.

Configurations 40 and 42 indicates the intruder at lengths F and C respectively of cable 8.

Configuration 37 and digital display 39 report a break in cable 8 at location D.

Only six loops are shown to describe the invention. The presence of more than one loop with incrementally

increasing length is an essential feature of the invention. Once this feature has been recognized, it becomes obvious for one of ordinary skill in the art to install such a system having many loops which excite many row areas.

The persistent photosensitive display 18 may be replaced by a matrix of photo-diodes, or equivalent, the output of which is processed by a computer and stored as a set of sub-arrays of 1 (lit) and 0 (dark), one sub-array corresponding to each row area A through F of display 18 of FIG. 1.

Digital displays 39 and 45 through 49, each comprise one column of integers, each such integer being equal to the sum of all the elements in one sub-array. The quasi-static quiescent state of configurations 36 and 44 then corresponds to a column of all 1's as shown by displays 45 and 47 respectively. These sums are recomputed periodically at some convenient interval, typically on the order of one second. A pattern of integers corresponding to the number of loops will signal the fact and locality of a disturbance of cable 8 as an attempted traverse of the protected line. This is demonstrated by configurations 36, 38, 40, 42 and 44 with their respective digital displays 45, 46, 48, 49 and 47. The automated interpretation of a digital output of the sort described above is well known in the art.

The local site computer 20 may receive the signals from the display 18 which correspond to the light pattern on each array to show the configuration. A cathode ray tube or a printer (not shown) of computer 20 may show the status of the active configuration. Configurations 36, 37, 38, 40, 42 and 44 are typical examples. Corresponding alphanumeric displays 31, 33, 35, 39, 41 and 43 indicate the status which is updated periodically. The computer display may be reset automatically to a quiescent state after the intrusion has been noted. The computer 20 display is accomplished by techniques well known in the art.

FIG. 4 shows another embodiment of the invention. A laser source of light 2 applies light energy to one end of a cable 4a comprising a multiplicity of multimode gradient index optical fibers 54. The beam passing down each length of fibers 54 in sensor cable 8a is reflected at the far end by a mirror 52, and retaining the essential off-axis beam characteristics is coupled out of that input fiber by a special directional coupler 50 and exits to display 18 between pairs of mirrors 32 as cable 6a. In this application it is essential that the nature and intensity of the coupled beam depends on the particular meander trajectory of the input beam, a quality normally deprecated in commercial couplers. The operation is then similar to that of the fiber loops 10, 12, 14, and 16 of FIG. 1. Here, single optical fibers differing in length by values of approximately L meters, enable the fact and location of the intrusion to be detected. It is understood that the computers 20 and 24 of FIG. 1 may readily be coupled to the system of FIG. 4.

The gradient index fiber coupler 50 should have a nominal coupling value on the order of about −10 dB. A marginally suitable commercial gradient index multimode coupler 50 is an Amphenol 946-110-2210. Design considerations for couplers especially designed for the present application have been developed in another connection. {Anro Engineering Consultants, Phase I Final Report Fiber Optic Multimode Feed for Monopulse LIDAR, Contract No. DNA001-87-C-0041, 30 Sept. 1987}

While the invention has been shown and described with reference to the preferred embodiment thereof, it will be understood by those skilled in the art that the above and other changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A perimeter protection system for use in indicating the location of an intrusion into a protected area, said system comprising:

a light source for generating a light beam;

display means having a plurality of display areas;

a plurality of multimode gradient index optic fiber loops, each varying in length from each other by predetermined amounts and having every portion highly sensitive and substantially uniformly sensitive to an external disturbance applied at any point, said each having an input end coupled to said source of light for receiving said light beam, and said each loop having an output end coupled to said display means for projecting said light beam propagated along the length of said each of said plurality of optic fiber loops onto a different one of said plurality of display areas,

said plurality of multimode gradient index optic fiber loops forming a cable and having said input and said output ends at one end of said cable, said cable being positionable around a periphery of said protected area, said plurality of multimode gradient index optic fiber loops being positioned in said cable so that the distance along the cable of successive loops is equal to said predetermined amounts,

said each of said plurality of multimode gradient index optic fiber loops when in an undisturbed state conducting said light beam which projects a first type of pattern from said second end and when disturbed projects a dynamically varying beam which produces a transient characteristic second type of pattern from said second end;

said display means sensing said first type of pattern projecting onto each of said plurality of display areas, indications representing that there was no intrusion into said protected area, and sensing said second type of pattern projecting onto one or more of said plurality of display areas, indications representing the location of the intrusion.

2. The system of claim 1 wherein said display means comprises:

said plurality of display areas each having a plurality of cells, each of said plurality of cells having means for sensing said light beam for display.

3. The system of claim 2 wherein said display means further comprises:

a plurality of pairs of reflecting means for reflecting said light beams from each of said second ends of said plurality of optic fiber loops onto said different one of said plurality of display areas,

said plurality of pairs of reflecting means being mounted in a parallel position to each other, and each of said pair being perpendicular to and bordering opposite boundaries of their respective display areas so that said each of said plurality of cells is adjacent to each of said pair, thereby optically isolating said each of said plurality of display areas from each other.

4. The system of claim 3 wherein said sensing means comprises:

photo-detector means responsive to said light beam for generating a visual indication of said each of said plurality of cells being exposed to said light beam.

5. The system of claim 4 wherein said each of said plurality of display areas having said visual indication representative of a transition from said first type of pattern to said second type of pattern, the location of the intrusion being representative of said one of said plurality of display areas at said transition having a multiplicity of visual indications.

6. The system of claim 5 wherein said sensing means further comprises:

said photo-detector means responsive to said light beam for generating an electrical signal for each of said plurality of cells being exposed to said light beam.

7. The system of claim 6 wherein said display means further comprises:

digital display means coupled to said each of said plurality of display areas for displaying a count of the number of said electrical signals received from said each of said plurality of display areas.

8. The system of claim 7 wherein said display means further comprises:

alphanumerical display means coupled to said each of said plurality of display areas for displaying a message indicating the location of the intrusion.

9. The system of claim 8 wherein said display means further comprises:

computer means coupled to said plurality of display areas and said alphanumeric display means and responsive to said electrical signals for providing indications representative of said transition, the location of the intrusion being representative of said one of said plurality of display areas at said transition generating a multitude of electrical signals, said computer means being responsive to said multitude of electrical signals for generating said message.

10. The system of claims 9 wherein displays of said first and said second types of patterns remain persistent and are updated after a predetermined time.

11. The system of claim 1 wherein said light source is a laser.

12. A perimeter protection system for use in indicating the location of an intrusion into a protected area, said system comprising:

a light source for generating a light beam;

display means having a plurality of display areas;

directional coupler means for directing said light beam;

a first plurality of optic fibers, said each having an input end coupled to said light source for receiving said light beam and an output end coupled to pass said light beam to said directional coupler means;

a second plurality of optic fibers, each varying in length from each other by predetermined amounts and having every portion highly sensitive and substantially uniformly sensitive to an external substance applied at any point, and said each having a First end coupled to said directional coupler means and propagating said light beam along the length of said each of said second plurality of optic fibers, said each of said second plurality of optic fibers having reflecting means coupled to a second end for reflecting said light beam the length of said each of said second plurality of optic fibers to said directional coupler means;

a third plurality of optic fibers having a third end coupled to said directional coupler means for receiving said light beam from corresponding fibers of said second plurality of optic fibers and having a fourth end coupled to said display means for projecting said light beam propagated along the length of said first, second and third plurality of optic fibers onto a different one of said plurality of display areas,

said second plurality of optic fibers forming a cable, said cable being positionable along a line adjoining or surrounding the precincts to be protected, said second plurality of optic fibers being positioned in said cable so that the difference in distance along the cable of successive lengths is equal to said predetermined amounts,

said second plurality of optic fibers when in an undisturbed state conducting said light beam which projects a first type of pattern from said fourth end and when disturbed projects a dynamically varying beam which produces a transient characteristic second type of pattern from said fourth end;

said display means sensing said first type of pattern projecting onto each of said plurality of display areas indications representing that there was no intrusion into said protected area, and sensing said second type of pattern projecting onto one or more of said plurality of display areas indications representing the location of the intrusion.

13. A method of protecting a precinct from intrusion, said method comprising the steps of:

A. Providing a light source;

B. Providing means for displaying visual indications within a plurality of display areas;

C. Providing a plurality of optic fiber loops, each differing in length by a predetermined amount and having every portion highly sensitive and substantially uniformly to an external disturbance applied at any point;

D. Gathering the loops in a cable with an input end and an output end at the same end of the cable;

E. Applying the light source to the input end;

F. Viewing the projections of a light beam that was propagated along each of said plurality of optic fiber loops onto a different one of said plurality of display areas;

G. Recognizing a first pattern indicating no disturbance along the length of the cable;

H. Recognizing a second pattern indicating that the cable was disturbed by an intruder and recognizing the location of the intrusion by the visual indications of the number of said plurality of optic fiber loops disturbed.

* * * * *

UNITED STATES DEPARTMENT OF COMMERCE
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WASHINGTON, D.C. 20231

# NOTICE OF APPROVAL OF EXTENSION REQUEST

Anro Engineering, Inc.
1800 Second St., Suite 965
Sarasota, FL 34236

ATTORNEY
REFERENCE NUMBER:

SERIAL NUMBER: 74/114421
MARK: PERIMETER PROTECTION FIBLOC ANRO ENGINEE
OWNER: ANRO ENGINEERING, INC.
EXTENSION REQUEST NUMBER: 2 NOTICE OF ALLOWANCE DATE: 12/03/1991

THE ABOVE NUMBERED EXTENSION REQUEST FOR FILING A STATEMENT OF USE HAS BEEN APPROVED BY THIS OFFICE.

THE APPLICANT HAS 18 MONTHS FROM THE MAILING DATE OF THE NOTICE OF ALLOWANCE TO FILE A STATEMENT OF USE.

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15 U.S.C. SECTION 1063(b)(2)

The MARK identified below was published for opposition under 15 U.S.C. Section 1062(a). No successful opposition was filed. In order to obtain a registration, Applicant must file a statement of use under 15 U.S.C. Section 1051(d)(1) within six months of the MAILING DATE OF NOTICE identified below. A six-month extension of time to file the statement of use will be granted upon proper request. Subsequent six-month extensions will be granted, for a period not to exceed twenty-four months, if good cause is shown. 15 U.S.C.1051(d)(2). Failure to timely file or perfect a statement of use or request for extension of time will result in abandonment of the application. The requirements for each are set forth at 37 C.F.R. Sections 2.88 and 2.8

74/114421

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ATTORNEY
REFERENCE NUMBER

## PLEASE REVIEW THE ACCURACY OF THE NOTICE OF ALLOWANCE DATA

A request for correction to the notice of allowance should be submitted within 30 days to the following address: COMMISSIONER OF PATENTS AND TRADEMARKS, WASHINGTON,D.C. 20231.The correspondence should be marked to the attention of BOX ITU. The Patent and Trademark Office will review the request and make corrections where appropriate.

**SERIAL NUMBER:** 74/114421 **MAILING DATE OF NOTICE:** 12/03/1
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**OWNER NAME:** ANRO ENGINEERING, INC.
**OWNER ADDRESS:** Suite 965
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009-fiber optic security system, comprising sensors, control panels and monitors which identify the point of intrusion

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